VOLUME XLII NUMBER 4

THE

ASTROPHYSICAL JOURNAL

An International Review of Spectroscopy and Astronomical Physics

NOVEMBER 1915

THE UNIVERSITY OF CHICAGO PRESS
CHICAGO, ILLINOIS, U.S.A.

AGENTS
THE CAMBRIDGE UNIVERSITY PRESS, LONDON AND EDINBURGH
KARL W. HIERSEMANN, LEIPZIG
THE MARUZEN-KABUSHIKI-KAISHA, TOKYO, OSAKA, KYOTO

THE
ASTROPHYSICAL JOURNAL
AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

CONTENTS FOR NOVEMBER 1915

VOL. XLII NO. 4

The Astrophysical Journal is published by the University of Chicago at the University Press during each month except February and August. ¶ The subscription price is $5.00 per year; the price of single copies is 65 cents. Orders for service of less than a half-year will be charged at the single-copy rate. ¶ Postage is prepaid by the publishers on all orders from the United States, Mexico, Cuba, Porto Rico, Panama Canal Zone, Republic of Panama, Hawaiian Islands, Philippine Islands, Guam, Samoan Islands, Shanghai. ¶ Postage is charged extra as follows: For Canada, 30 cents on annual subscriptions (total $5.30), on single copies, 3 cents (total 68 cents); for all other countries in the Postal Union, 62 cents on annual subscriptions (total $5.62), on single copies, 11 cents (total 76 cents). ¶ Patrons are requested to make all remittances payable to The University of Chicago Press, and in case a check is drawn on other than a Chicago or a New York bank to add 10 cents to cover a charge which we are obliged to bear as the cost of collection. For this reason they should use express money orders or bank drafts as preferred forms of exchange.

The following agents have been appointed and are authorized to quote the prices indicated:

For the British Empire: The Cambridge University Press, Fetter Lane, London, E.C. Yearly subscriptions, including postage, 23s. each; single copies, including postage, 3s. 3d. each.

For the Continent of Europe: Karl W. Hiersemann, Königstrasse 29, Leipzig, Germany. Yearly subscriptions, including postage, M. 23.60 each; single copies, including postage, M. 3.10 each.

For Japan and Korea: The Maruzen-Kabushiki-Kaisha, 11 to 16 Nihonbashi Tori Sanchome, Tokyo, Japan. Yearly subscriptions, including postage, Yen 11.25 each; single copies, including postage, Yen 1.50 each.

Claims for missing numbers should be made within the month following the regular month of publication. The publishers expect to supply missing numbers free only when they have been lost in transit.

Business correspondence should be addressed to The University of Chicago Press, Chicago, Ill.

Communications for the editors and manuscripts should be addressed to the Editors of THE ASTROPHYSICAL JOURNAL, Yerkes Observatory, Williams Bay, Wisconsin.

Entered as second-class matter, January 17, 1895, at the Post-office at Chicago, Ill., under the act of March 3, 1879

THE
ASTROPHYSICAL JOURNAL
AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

VOLUME XLII — NOVEMBER 1915 — NUMBER 4

THE VISIBILITY OF RADIATION IN THE RED END OF THE VISIBLE SPECTRUM

By EDWARD P. HYDE and W. E. FORSYTHE

It has long been recognized that the sensibility of the average eye for radiation varies with the wave-length, the sensibility being a maximum in the yellow-green region of the spectrum and falling off to quite small values at each end of the spectrum. If the total radiation, measured in energy units for the wave-length interval whose center is at λ, be denoted by J_λ, and the luminous intensity measured in light-units for the same interval by I_λ, then the sensibility of the eye for the same interval is

$$V_\lambda = \frac{I_\lambda}{J_\lambda}.$$

The determination of the ratio V_λ, termed the visibility of radiation, has been made in a number of investigations among which may be mentioned particularly those of König,[1] Langley,[2] Bender,[3] Ives,[4] and Nutting.[5]

The methods used to obtain the value of I_λ in this ratio may be divided into two classes. One involves a direct comparison, as in

[1] König, A., *Ges. Abhandlungen.*

[2] *Amer. Jour. Sci.*, **36**, 359, 1888.

[3] *Annalen der Physik*, **17**, 105, 1914. See also Thurmel, *ibid.*, **33**, 1139, 1910.

[4] *Phil. Mag.* (6), **24**, 853, 1912.

[5] *Ibid.*, **29**, 301, 1915.

the ordinary "equality of brightness" photometer, of the illumination produced by light of successive wave-lengths in the visible spectrum with that produced by another source taken as a standard. The other method involves the use of the flicker photometer in which the criterion of equality is the disappearance of flicker. In either case the light from the comparison source may be kept constant in color, or the step-by-step method may be employed, in which case the color of the comparison source is changed at those points where the color difference exceeds a predetermined amount.

The direct-comparison method was used by König and by Langley, while Ives, Bender, and Nutting have used the flicker method. Although much work has been done on the subject, there seems to be some doubt as to whether these two methods give the same result for very great color differences; indeed, it has been shown that in certain cases they do not.[1] The measurements have extended from $0.4\,\mu$ to $0.7\,\mu$, though the data near these limits as determined by Nutting, who has carried his measurements farther than anyone else, are given only to one significant figure.

The great difficulty in the way of determining the visibility relation far out in the red or blue end of the spectrum is the small amount of light available. When it is realized that the sensibility of the eye varies by a factor of about 48,000 in going from the position of maximum sensibility to about $0.77\,\mu$, as may be seen by considering the results of others in conjunction with those given below, it will be evident that a source that would be very luminous taken as a whole would be quite weak if only a small interval of wave-length were taken in the deep red. The same considerations apply to the deep blue.

In connection with a problem in optical pyrometry recently investigated in this laboratory,[2] it was important to know the visibility-curve somewhat beyond $0.7\,\mu$ and to be certain of the value to a reasonable degree of accuracy. To this end the present investigation was undertaken, making use of an adaptation of the arrangement employed in the Holborn-Kurlbaum optical pyrometer. The advantage in using the method of optical pyrometry is

[1] Luckiesh, *Electrical World*, **67**, 621, 1913. *Physical Review* (2), **4**, 1, 1914.

[2] *Astrophysical Journal*, **42**, 294, 1915.

twofold. In the first place, and in general, may be mentioned the availability of greater brightness, which permits the extension of the measurements farther into the red end of the spectrum; and in the second place by this method the sensibility-curve is obtained under conditions as to size of field and method of making the measurements very similar to those of the problem that was being investigated. Although, in accordance with the present needs, measurements were confined to the red end of the spectrum, the method might be employed also in extending the visibility-curve in the region of short wave-lengths.

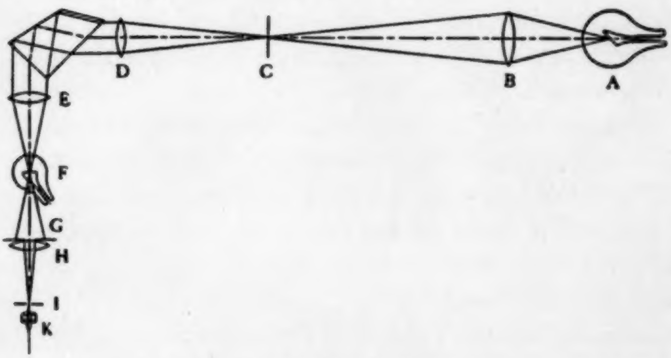


FIG. 1.—Arrangement of apparatus

In Fig. 1 is shown the arrangement of the apparatus used. The spectrum of a broad vertical carbon filament (A) is formed by means of a Hilger constant-deviation spectrometer in the focal plane of the object-glass of the telescope, in which plane is placed the horizontal filament of a second lamp (F). A lens (H) projects an image of this filament and of the background spectrum on a narrow vertical slit (I), in the focus of the eyepiece (K). By rotating the drumhead of the spectrometer, any spectral region of (A) may thus be brought into the field of view and compared in brightness with the pyrometer filament operated at a constant current. The brightness of the lamp filament (A) was kept constant for the entire determination. After the brightness of the lamp filament (F) that would apparently equal that of a region far out in the red end of the spectrum of the filament (A) had been determined, this lamp

filament (F) was maintained at that constant brightness, and different spectral regions of filament (A) were compared with this brightness. This was accomplished by reducing the apparent brightness of the lamp (A) by means of rotating sectored disks placed between the carbon filament (A) and the collimator slit (C) of the spectrometer and quite close to the latter, and then finding the position of apparent equality by turning the drumhead. The filament of lamp (A) was about 1.6 mm wide and about 0.3 mm thick, requiring 9.6 amperes for a black-body color-match temperature of 1940° K., a temperature which was used throughout. This lamp was matched in color with a standard lamp several times during the course of the observations and, as closely as could be determined, it remained constant. The collimator slit (C) was for the greater part of the work kept at an opening of 0.5 mm. As a magnification of about one and one-half was used with the lens (B), it can be seen that the slit was at all times much more than filled. The lamp filament (F) was of tungsten, 0.06 mm in diameter. The brightness of the filament (F) used for the most part corresponded to a color-match with a black body at about 1300° K. Determinations were also made with this lamp filament at about one-half, twice, and four times this brightness. These four determinations all checked well within the limits given below. The eyepiece slit was maintained at an opening of 0.2 mm because if wider eyepiece slits were used, variations across the slit could be noticed. Before and after each set of observations the calibration of the spectrometer was tested by means of known spectral lines.

The energy-curve of the lamp (A) was determined by comparison with a black body. Using the temperature thus obtained the energy-distribution was calculated from Wien's equation, taking C_2 equal to 14,500. In reducing the observed luminosities, corrections were made for dispersion, slit-widths, selective absorption of the lenses and prisms, and scattered light. It has been shown[1] that in certain cases an error may be made owing to diffraction of the light around the pyrometer filament. This error depends upon the size of the pyrometer filament, the angle of the incident radiation, and the wave-length. In the present investigation the size of the

[1] *Physical Review* (2), 4, 163, 1914.

filament and the incident angle were large enough to make this error negligible over the range of wave-lengths used. In correcting for the scattered light, two methods were used. First, the brightness of the scattered light was measured as follows: the field of the spectrum was limited in height by a diaphragm in front of the slit (C) and the filament (F) moved up above the spectrum so that it could be compared with the brightness of the scattered light alone. By varying the current through the lamp filament (F) the brightness of this scattered light could be compared with that of the direct radiation plus the scattered light. Inasmuch as the lamp filament (F) was moved out of its position, the brightness of the scattered light that was compared may have been somewhat different from that at the center of the spectrum. However, results by this method check very closely with those of the method described below. The second method of correcting for the scattered light was to use before the eyepiece (K) a red glass of known transmission which would absorb all the more luminous parts of a scattered radiation. These two methods gave results for the scattered light that amounted to about 20 per cent at $\lambda = 0.76\ \mu$ for a particular length of slit (C). The illumination of the retina was well beyond the region where the Purkinje phenomena are effective, as indicated by the data given above, and the size of the field was extremely small for the comparison source, corresponding to the filament (F) (diameter 0.06 mm) magnified six times by the eyepiece, giving in angular units a field of about 0.4 degrees.

As has been shown by the work of Ives[1] and others, it would be expected that the Purkinje effect would be very small even for low illuminations with this small field. As the same results were obtained with lamp (F) at one-half, at twice, and at four times the mean intensity used, it is seen that conditions were well outside of those in which the Purkinje effect is found.

Measurements were made by nine observers whose final results, reduced to a common value at $\lambda = 0.64\ \mu$, are shown in Table I. Each observer made determinations with at least two intensities of lamp (F) and also check-settings at these intensities, yielding for each observer at least four separate determinations on different

[1] *Phil. Mag.* (6), **24**, 173, 1912.

days. In making a single determination, observations were made with nine sectors and check-readings were made with at least five sectors. In working up the data, curves for the two intensities were made equal for the region where they overlapped. From a number of readings of the ordinates of the two curves, the mean ratio was calculated, giving the constant by which the luminosities differed. The variation of this ratio from a constant value was used in part to determine the accuracy of the work. The values given in Table I are the mean of the values read from smooth curves thus obtained, made equal to 100 at $\lambda = 0.64\,\mu$.

TABLE I

Visibility Data on 9 Subjects in the Red End of the Spectrum

Wave-Lengths	(1) E.P.H.	(2) W.E.F.	(3) F.E.C.	(4) A.G.W.	(5) M.L.	(6) C.F.S.	(7) R.G.B.	(8) W.W.	(9) H.M.J.
0.620..	245.0	245.0	255.0	211.0	265.0	252.0	297.0	291.0	237.0
.630..	164.0	163.0	155.0	151.0	171.0	159.0	178.0	174.0	161.0
.640..	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
.650..	59.0	56.0	59.0	59.0	57.0	59.0	53.0	56.0	61.0
.660..	32.0	31.0	29.0	32.0	26.0	32.0	27.0	30.0	32.0
.670..	16.8	15.3	15.8	16.3	14.4	16.8	13.7	15.6	16.6
.680..	8.3	7.5	7.8	8.0	7.1	8.2	6.8	8.1	7.8
.690..	4.1	3.6	3.8	4.0	3.5	4.1	3.4	4.0	3.7
.700..	2.05	1.73	1.87	1.96	1.77	1.86	1.61	1.90	1.88
.710..	1.01	0.86	0.92	0.95	0.86	0.94	0.86	0.93	0.90
.720..	0.49	0.42	0.46	0.48	0.41	0.46	0.42	0.46	0.44
.730..	0.24	0.21	0.22	0.24	0.21	0.22	0.20	0.23	0.21
.740..	0.12_1	0.10_8	0.11_3	0.11_7	0.10_4	0.11_2	0.10_4	0.11_4	0.10_7
.750..	0.06_1	0.05_2	0.05_7	0.05_8	0.05_3	0.05_5	0.05	0.05_6	0.05_5
.760..	0.03_1	0.02_6	0.03_0	0.03_0	0.02_7	0.02_7	0.02_9	0.02_8	0.02_9
0.770..	0.01_7	0.01_3	0.01_5	0.01_6	0.01_4	0.01_2	0.01_4	0.01_2	0.01_4

To show the relative values of the sensibility of the individual observers in the red end of the spectrum Table II is given. In obtaining these data, both lamp (*A*) and lamp (*F*) were kept constant, (*F*) being at the average brightness used, and settings were made by each observer. Data were thus obtained in the form of curves from which could be computed the relative values of the sensibility of different observers at $\lambda = 0.75\,\mu$. It will thus be seen that the values given are for the relative sensibility of the different observers when comparing the brightness of the particular spectral color with the brightness of lamp (*F*). As previously stated, the values given

in Table I are also relative. It will be seen from a comparison of Tables I and II that, though there was a great variation in the values given by the individual observers to the luminous intensity in the

TABLE II

RELATIVE VALUE OF THE SENSIBILITY OF THE DIFFERENT OBSERVERS FOR LIGHT AT $\lambda=0.75\,\mu$ WHEN COMPARED WITH THAT FROM A BLACK BODY AT ABOUT 1300° K.

E.P.H	113
W.E.F	157
F.E.C	170
A.G.W	192
M.L	123
C.F.S	125
R.G.B	78
W.W	122
H.M.J	84

extreme red, the relative values do not vary so widely. The average results of the nine observers, together with the values obtained in previous determinations, are shown in Table III. For comparison the values of the previous determinations have also been

TABLE III

VISIBILITY DATA IN THE RED END OF THE SPECTRUM

Wave-Lengths	Mean Visibility of 9 Subjects	Mean Values Given by Nutting	Mean Values Given by Ives	König's Values
0.620	252.0	227.0	221	189
.630	164.0	164.0	156	143
.640	100.0	100.0	100	100
.650	58.0	62.0	59	61
.660	30.0	34.0	39*	33
.670	15.7	18.6	25*	15
.680	7.6	$8._0$	15*	....
.690	3.8	$4._7$	....	....
.700	1.87	$1._3$	....	....
.710	0.91	....	....	....
.720	0.45	....	....	....
.730	0.22	....	....	....
.740	0.11_1	....	....	....
.750	0.05_5	....	....	....
.760	0.02_9	....	....	....
0.770	0.01_4	....	....	....

* Extrapolated values.

reduced to 100 for $\lambda = 0.64\,\mu$. The average results of the nine observers were computed by taking the arithmetical average of the values given in Table I. As the relative values differed by such a small amount, this method will give approximately the same results as the method of reduction to equal areas.

In determining the accuracy, consideration has been given first of all to the necessary corrections together with the accuracy with which they could be obtained; secondly, to the error which the different observers made in setting the drum of the spectrometer for a match of brightness in the different parts of the spectrum; thirdly, to the agreement of observations taken on different days; and, fourthly, to the agreement of the data obtained with different intensities of the lamp (F). From a consideration of all the foregoing it would seem that the accuracy of the resulting sensibility-curve ranges from about 5 per cent at $0.62\,\mu$ to about 15 per cent at $0.76\,\mu$. How nearly the final curve could be classed as an average curve is a question. The observations are those of nine men, and, as can be seen, the different observers have quite a range of sensibility. It will be noticed that observer 4 is quite sensitive to red radiation, while observer 7 is very sensitive to the blue-green part of the spectrum. It is doubtful if multiplying the number of observers would change the curve by a very great amount. To make this point certain it would be necessary to have quite a number of observers, and at the time this was not feasible. All of the observers with the exception of the last two have had considerable experience in photometric work and with instruments of similar optical character. These two have had much to do with optical apparatus, but have not had so much photometric experience.

The agreement as shown in Table III between the values given and those obtained by other investigators within the common region is as good as might be expected. The agreement in the present work among the different observers in measurements in the red is probably better than that attainable in the more luminous region of the spectrum where the color differences are much more pronounced. It should be remembered that the agreement referred to pertains to the relative visibility in different wave-lengths of the red region rather than to the visibility in the red region compared

with the visibility of white light, which was shown to be markedly different for different observers. Emphasis should be laid on the fact that the data given have been obtained with a small field. It is probable that the same result would be obtained with larger fields.

SUMMARY

Data have been given for the visibility-curves for 9 observers from $0.62\,\mu$ to $0.77\,\mu$, together with the relative values for the sensibility of the individual observers when comparing light at $0.75\,\mu$ with that from a black body at about 1300° K. These results have been compared with the results of other determinations in the common region.

NELA RESEARCH LABORATORY
NATIONAL LAMP WORKS OF GENERAL ELECTRIC CO.
NELA PARK, CLEVELAND, OHIO
April 1915

THE EFFECTIVE WAVE-LENGTH OF TRANSMISSION OF RED PYROMETER GLASSES AND OTHER NOTES ON OPTICAL PYROMETRY

By EDWARD P. HYDE, F. E. CADY, and W. E. FORSYTHE

A. THE EFFECTIVE WAVE-LENGTH OF TRANSMISSION OF RED PYROMETER GLASSES

In working with any optical pyrometer it is in general sufficient to use an approximately monochromatic screen between the eye and the pyrometer filament or other comparison source in order that the latter may apparently match in color the source studied. The glass or screen used must be much more nearly monochromatic for studying sources at high temperatures, as it is in this region that the differences in color of the various sources are more noticeable. An optical pyrometer can be so calibrated and so used as to make unnecessary a knowledge of the extent to which the screen is monochromatic. To do this it is necessary to use in calibrating the pyrometer a black-body furnace that can be operated at various temperatures up to the highest temperature for which the pyrometer is to be used. However, if an attempt is made either to calibrate the pyrometer by the aid of a black-body furnace held at a single temperature,[1] as for instance the melting-point of palladium, or to extend the temperature measurements beyond that of the standard furnace by means of absorbing glasses or rotating sectored disks, a knowledge of the effective wave-length for the screen used is necessary. In attempting to check the calibration of a Holborn-Kurlbaum optical pyrometer using a black-body furnace, differences much greater than could be ascribed to errors of observation were encountered. Pyrometer readings were made with the black body held at the temperature of melting palladium, using various rotating sectored disks. The scale thus obtained was tested by direct comparison with the same furnace held at the temperature of melting gold, and found to be in error by several

[1] C. E. Mendenhall, *Physical Review*, 33, 74, 1911.

degrees. In this case the value for the effective wave-length of the red screen used was obtained with a spectrometer as outlined below. An investigation of the causes of the error led to the following study of the effective wave-length of transmission of the red glass used.

Various definitions have been given to this effective wave-length. It has been identified[1] with the maximum of luminosity as determined with a spectrometer. This maximum of luminosity is determined by so mounting the screen with respect to the spectrometer that a direct observation of the wave-length of maximum brightness of the transmitted light can be obtained for any particular spectral distribution. It has also been defined[2] as the center of gravity of the luminosity as transmitted through the screen, this center of gravity being determined in various ways. Further, an attempt has been made to associate it with a definite distribution,[2] i.e., a definite temperature of the incident radiation, the value of the wave-length being determined by computation.

The foregoing definitions and methods will not in general give the effective wave-length; in fact it can be shown that in nearly all cases they will not give the wave-length which must be used to calculate temperatures. The wave-length that should be used is one such that for any definite temperature interval for a particular source the ratio of the radiation intensities for this wave-length shall equal the ratio of the integral luminosities through the screen used. This is evident when it is remembered that the quantities which are actually compared are the integral luminosities as observed through the screen, and therefore, in computation, a wave-length should be used for which the ratio is the same. Defining the effective wave-length in this manner leads to the same result for the given temperature interval as would be obtained if the screen used were absolutely monochromatic in this wave-length.

The screens furnished with optical pyrometers are not monochromatic. Among the glasses commonly used for red screens are

[1] Waidner and Burgess, *Bulletin Bureau of Standards*, **3**, 163, 1909; see also Mendenhall, *loc. cit.*

[2] Pirani, *Verh. der deutschen physikalischen Gesellschaft*, **15**, 826, 1913.

Jena "Kupferrubin" glass No. F-2745 and Jena "Rotfilter" No. F-4512. The transmission of a specimen, 2.9 mm thick, of what was furnished by the makers as "Rotfilter" glass No. F-4512 is shown in curves *A* and *A′* in Fig. 1. Three methods have been employed to obtain the transmission of the red glass: (1) the spectrophotometric, (2) the spectral pyrometric, and (3) the spectrobolometric.

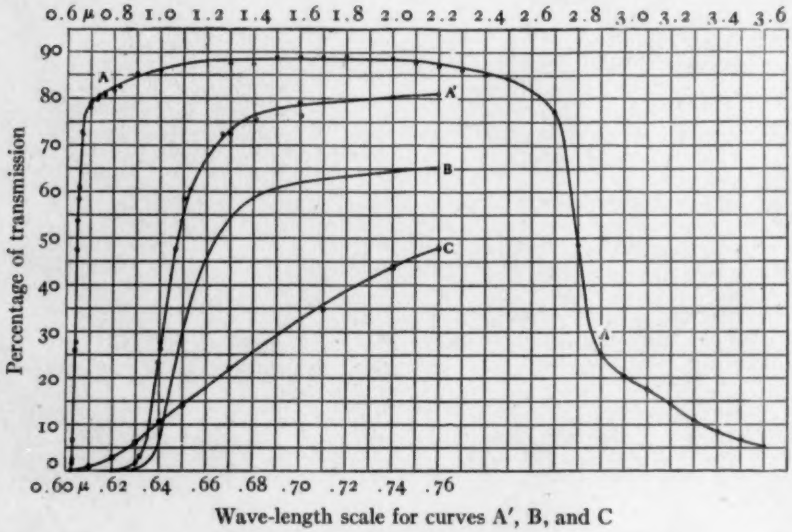


Fig. 1.—Transmission of red pyrometer glasses

A Transmission of single piece F-4512 red glass
A′ Same as A; larger wave-length scale
B Transmission double thickness of same glass
C Transmission of single thickness of red pyrometer glass, probably F-2745

The agreement of the three methods can be seen from curve *A*, Fig. 1, where the transmissions obtained by the different methods are marked differently. The transmission of two thicknesses of the glass (5.8 mm) in the visible spectrum is given by curve *B*. In curve *C* is shown the transmission of what is supposed to be "Kupferrubin" glass No. F-2745. This is a piece of the same sample of red glass as has been used[1] in a comparison of the temperature scale based on the Wien radiation law as applied to an optical pyrometer and a scale based on the Stefan-Boltzman law.

[1] Mendenhall and Forsythe, *Physical Review* (2), 4, 62, 1914.

It is seen that the transmission band is rather broad, though the apparent breadth, as observed with a spectrometer, is much less, owing to the limit of vision. It has been recognized by Waidner and Burgess,[1] Pirani,[2] and others that, owing to the breadth of the transmission band, the effective wave-length is subject to change with changes in spectral distribution of the incident radiation, as occasioned by changes in temperature of the radiating sources under investigation. In fact, Waidner and Burgess have attempted to show how this wave-length changes with the change of the temperature of the source by the use of the spectrometer as outlined above. In this way they found that the effective wave-length seemed to become longer at higher temperatures, a result quite contrary to expectations.

The importance of knowing in accurate measurement in pyrometry the effective wave-length for different ranges of the temperature is evident. It was desired to determine the effective wave-length for the red glass for the interval between two definite temperatures of a black body and to determine how this effective wave-length changes as this interval is changed. Two methods were employed: (1) that of direct measurement, and (2) that of computation, assuming a knowledge of the visibility-curve of the eye. An electric incandescent lamp at two arbitrary currents, corresponding in energy distribution to the black body at 1600° K. and at 2000° K. respectively, was selected as the source, and measurements were made with the best or most nearly monochromatic glass in our possession, viz., that for which the transmission-curve is given in Fig. 1 (curve *A*) and of the kind known as Jena "Rotfilter" No. F-4512. A double thickness of glass (5.8 mm) was used, as this is about the thickness of glass generally employed.

By the first method, the ratios of intensities of emission of the source for a number of wave-lengths at the two temperatures were measured, and these ratios compared with the ratio of integral luminosities of the radiation from the source observed through the double thickness of glass. These measurements were carried out with two distinct sets of apparatus. In one set of measurements the ratios of the intensities of radiation were measured with a

[1] *Op. cit.* [2] *Op. cit.;* see also *ibid.*, 17, 47, 1915.

spectrophotometer, and the ratio of the integral luminosities was determined with a Lummer-Brodhun photometer having the double thickness of red glass in the eyepiece. In the other set of measurements the ratios of the intensities of radiation were determined with a spectral pyrometer[1] and the ratio of the integral luminosities was measured by the use of a laboratory form of the ordinary Holborn-Kurlbaum pyrometer having two thicknesses of the red glass in the eyepiece.

By the second method the integral luminosities through the red glass at the two chosen temperatures were computed from a knowledge of the spectral energy-curves (computed from Wien's equation), the transmission-curve for the glass (Fig. 1, curve *B*), and the sensibility-curve of the eye. Inasmuch as the best published visibility data extend only to 0.7 μ and are given only to one significant figure in this neighborhood, which is most important in the present investigation, a preliminary investigation of the sensibility of the eye in this region was undertaken.[2] The data obtained in this preliminary investigation were used in the present computations.

The results obtained by the two methods, direct experiment and computation, are given in Table I.

TABLE I

EFFECTIVE WAVE-LENGTH OF MONOCHROMATIC TRANSMISSION FOR TWO PIECES OF RED PYROMETER GLASS NO. F-4512, 5.8 MM TOTAL THICKNESS, FOR THE INTERVAL BETWEEN THE TEMPERATURES 1600° K. AND 2000° K.

Direct experiment, using spectrophotometer	0.664 $\mu\pm$0.001 μ
Direct experiment, using pyrometer	0.663_5 $\pm$0.001
Computed value	0.663_8
Mean	$0.663_8\mu\pm$0.001 μ

The next point of interest lies in the variation of this effective wave-length with change in temperature of the source studied. These variations can be determined most accurately by the method of computation, and as the changes in effective wave-length are

[1] Henning, *Zeitschrift für Instrumentenkunde*, **30**, 61, 1910.

[2] *Astrophysical Journal*, **42**, 285, 1915.

small it is unnecessary to give the value for more than a few temperature intervals. In Table II are given the results of these computations, assuming the effective wave-length between 1600° K. and 2000° K. to be the mean value given in Table I. Because of interest in the paper already referred to in connection with some work by C. E. Mendenhall and one of the authors, the changes in the effective wave-length of transmission of the red glass used in that work have been computed. These results are also given in Table II.

TABLE II

COMPUTED CHANGES DUE TO VARIATION IN THE TEMPERATURE INTERVAL IN THE EFFECTIVE WAVE-LENGTH OF TWO SAMPLES OF RED PYROMETER GLASS USING TWO THICKNESSES OF EACH

Temperature Interval	Glass No. F-4512 Total Thickness 5.8 mm	Glass No. F-2745 Total Thickness 6.7 mm
1336°–1600° K.	0.664_9	0.667_1
1336°–1822° (gold to palladium)	$.664_6$	$.666_7$
1336°–3100°	$.663_4$	$.664_6$
1600°–1822°	$.664_1$	$.666_1$
1822°–2400°	$.662_9$	$.663_6$
1822°–3100°	$.662_4$	$.662_7$
2400°–3100°	0.661_7	0.661_5

Observations made on other pieces of glass used with the Holburn-Kurlbaum and other pyrometers indicate quite appreciable deviations from the particular specimens studied in the present investigation. As obviously it would be most inconvenient to subject every sample of glass to such an investigation as that recorded here, it appears desirable to find a simple way of calibrating glasses in terms of the specimen already investigated. This can be done readily, by determining the ratio of the apparent candle-powers of a standard lamp at two definite currents, using the glass under investigation in the eyepiece of a Lummer-Brodhun or other suitable photometer, and comparing this observed ratio with the known ratio as determined with the known sample of glass in the eyepiece of the photometer. If the ratio with the test glass is found to be, say, 1 per cent greater than the given ratio for the standard glass, then the effective wave-

length for the temperature interval corresponding to the two currents through the lamps must be shorter than the accepted wave-length of the standard glass by an amount readily computed from Wien's equation and from the known black-body color-match temperatures of the lamp at the two currents. Until the standardization of glasses may be undertaken by the Bureau of Standards, Nela Research Laboratory will be glad, for the convenience of other investigators, to calibrate red glasses in terms of our standard; or else will, if desired, furnish at cost lamps calibrated between two definite currents, giving the black-body color-match temperatures and the ratio of apparent candle-powers as determined with the standard red glass in the eyepiece.

Using a sample of red glass (No. F-4512) slightly thicker than the standard sample here investigated, the ratio of the intensities of the radiation through the glass from a black body at the temperature of melting palladium and at the temperature of melting gold has been determined. In determining this ratio four different pyrometer lamps have been used, three of tungsten and one of carbon. Four different black-body furnaces have been used. At times the same furnace was used for the two points and at other times different furnaces. As a final result of ten determinations extending over a year and a half, 76.9 was obtained for this ratio. Using this value, 76.9, the effective wave-length for this temperature interval for the red glass employed together with the two temperatures, C_2 of Wien's equation may be computed. Thus C_2 was found to be 14,460, a value that checks well with the latest determinations.[1]

By computation, as shown above, the effective wave-length can be determined for any range of distribution of radiation, that is, any range of temperature. In some work it is very desirable to know the effective wave-length as a certain temperature is approached. If the effective wave-lengths are computed for the intervals 1500° K. to 1300° K., 1500° to 1700°, 1500° to 1800°, etc., and these values are plotted as a curve between effective wave-lengths and temperature difference from 1500° K., this curve would pass through the 1500° point and could be used to obtain the

[1] Coblentz, *Bulletin Bureau of Standards*, 10, 1, 1914.

effective wave-lengths for 1500° K. By computing a series of such limiting effective wave-lengths the data given in Table III were obtained.

TABLE III

LIMITING VALUE OF EFFECTIVE WAVE-LENGTH AS DIFFERENT TEMPERATURES ARE APPROACHED

Temperatures	Limiting Effective Wave-Lengths
1300° K.	$0.665_5\mu$
1500°	$.664_8$
1700°	$.664_1$
1900°	$.663_5$
2300°	$.662_4$
2700°	$.661_6$
3100°	0.661_3

As a test of the correctness of the value of the effective wave-length obtained and its variation with the temperature interval, a pyrometer lamp was carefully calibrated, using rotating sectors, against a black-body furnace held at the temperature of melting palladium. This same furnace was held at two temperatures lower than this temperature, and its temperature was determined by the application of Wien's equation, going down from the temperature of melting palladium and also up from the temperature of melting gold, as determined for the same furnace. The results are given in Table IV. For the temperature interval between 1822° K. and

TABLE IV

TEMPERATURES OF BLACK-BODY FURNACE AS DETERMINED BY COMPUTATION FROM TWO FIXED POINTS

Temperatures from Palladium Point	Temperatures from Gold Point
1721° K.	1720° K.
1625°	1625°

1336° K. the effective wave-length for this interval given in Table II has been used, and for C_2 the value given above. A reference to Table II will show that there is a very small change in the effective wave-length for smaller intervals within this same interval.

B. THE TEMPERATURE COEFFICIENT OF TRANSMISSION OF RED PYROMETER GLASS

In connection with the investigation described above it was observed that the transmission of the red pyrometer glass, presumably made with copper oxide, and dependent for the color on a colloidal solution, is subject to a large change with temperature. This has not been investigated thoroughly, but observations were made at two temperatures, 20° C. and 80° C., by immersing the glass in water heated to these two temperatures. The results are given in Fig. 2. Curve *A* is the transmission of the glass at the lower temperature 20° C., and curve *B* the corresponding curve at the higher temperature 80° C. The transmission is shown to decrease with increase in temperature, the coefficient of change of temperature being greatest in the shorter wave-lengths. The change is such as to make the transmission band appear to shift to longer wave-lengths as the temperature is increased. A further investigation of this should give data with which to test the theoretical formula of Mie[1] for colloidal solutions.

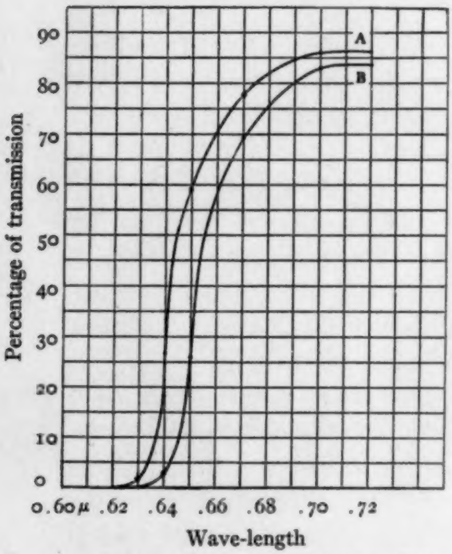


FIG. 2.—Transmission of single thickness of glass F-4512: A at 20° C.; B at 80° C.

A test was made of the effect of this temperature-shift of the transmission band on temperature-measurements when the red glass was used as a screen before the eyepiece of the pyrometer. The temperature of a broad carbon filament lamp operated at an apparent temperature of 1900° K. was measured with the red glass used as a screen before the eyepiece of the pyrometer. It was so arranged that the red glass could be used at room temperature

[1] *Annalen der Physik*, **25**, 377, 1908.

and also when heated to about 80° C. The temperature of the lamp was measured using a 2° sectored disk, as this would give a larger effect than a sector with greater transmission. It was found that there was a decrease of 5° C. in the temperature obtained when the glass was heated to 80° C., over that obtained with the glass at room temperature. From this it will be seen that for all ordinary temperature changes the effect would be negligible.

C. INFLUENCE OF POSITION OF ROTATING SECTORED DISK IN USE WITH THE HOLBORN-KURLBAUM TYPE OF PYROMETER

If a rotating sectored disk is used with an optical pyrometer to reduce the intensity of the source, care must be taken as to the location of the disk. There is a very marked difference in the results of temperature measurements, depending upon whether the sector is located near the projection lens or as near as possible to the pyrometer lamp. There is also a difference depending upon the relative position of the openings in the sector and the source, providing the source is a lamp filament. If a sector of small transmission is mounted near the lens and so placed that the openings of the sector are parallel to the axis of the filament when passing across the center of the lens, the definition is very bad, while if the openings of the sector are turned through 90° so that they are perpendicular to the axis of the filament, the definition is apparently quite good. When the rotating sector is located near the pyrometer lamp the definition is good and practically independent of the position of the openings of the sector. If a very large source, as for example a black body, is used, no such effect is to be noted. It would appear that the rotating sector as used with the optical pyrometer[1] has at times been placed in a position which would lead to uncertainties.

If a lamp filament used as a background be set so that it has the same brightness as a black body at 1822° K. (the temperature of melting palladium), as determined by the optical pyrometer using red glass before the eyepiece, and this background again set at the brightness corresponding to the melting-point of gold as indicated by the black body, the relation between the brightness of

[1] C. E. Mendenhall, *loc. cit.*

the lamp at the two temperatures, as determined by the rotating sector if placed near the lens, is not the same as that for a black body or other large source over the same range. Thus it was found that with the rotating sector located near the projection lens the error amounted to about 8° for this interval. The disk was so mounted that the openings made an angle with the axis of the pyrometer of about 45° when crossing the lens. The filament of the lamp used as a background was about 0.3 mm in diameter. However, if the sector be located very near the pyrometer lamp the ratio as found checks very closely with that for a black body.

SUMMARY

Data have been determined for the effective wave-length for Jena "Rotfilter" No. F-4512 and Jena "Kupferrubin" glass No. F-2745 for the interval corresponding to a black body at temperatures 1600° K. and 2000° K. The effective wave-lengths for different temperature intervals have also been computed for these two glasses. In connection with the work a determination of the constant C_2 of the Wien radiation law has been made.

It has been shown that care must be taken as to the location of the sectored disk when it is used to extend the temperature measurements with the optical pyrometer, and that the transmission of red glass used in such pyrometers is subject to change with change of temperature, although this effect does not lead to appreciable errors under the conditions ordinarily encountered.

Nela Research Laboratory
National Lamp Works of General Electric Co.
Nela Park, Cleveland, Ohio
April 1915

ON SOME PECULIARITIES OF THE RESIDUAL RADIAL VELOCITIES OF STARS OF DIFFERENT SPECTRAL CLASSES AND THEIR RELATION TO THE SOLAR MOTION

By C. D. PERRINE

While investigating the relation between radial velocities and magnitudes, I noticed in some of the classes what appeared to be a tendency of the velocities in some regions to differ systematically from those in other regions. Further examination confirmed the earlier suspicions and led to an examination of all of the classes.

It is the purpose of the present paper to point out some of the peculiarities found.

As the stars of Class B have such a strong preference for the Milky Way, they were examined first, as showing more readily peculiarities in widely separated and distinct regions of the sky.

The mean ***residual*** velocities and mean ***inherent*** velocities of all these stars were first grouped in quadrants as in Table I.

TABLE I

STARS OF CLASS B

	No.	Residual V_s	Mean V_2
		km	km
21^h– 3^h	34	−3.04	6.17
3 – 9	79	+0.26	5.29
9 –15	53	+1.78	6.50
15 –21	59	−0.18	7.86

The velocities used are from Campbell's catalogues, of Class B stars in *Lick Observatory Bulletin*, No. 195, of Class A in *Bulletin* No. 211, and of 915 stars of Classes F, G, K, and M in *Bulletin* No. 229.

These results indicate a systematic tendency, both in the general mass motions and in the average inherent velocities.

The *average* radial velocity (mean V_2) appears to be a minimum not far from the solar antapex and a maximum near the apex—

the velocities midway between these points being approximately the same and a mean between the maximum and minimum values. The significance of any such eccentricity of velocity, if confirmed, would be very great indeed.

The stars in the different classes were then cleared of the solar motion upon a common hypothesis for all.

An examination of the velocities and constant errors obtained by Campbell[1] shows an apparent relation between the solar motion and the K-term which will be referred to later. He concluded, however, that for all of the classes (all stars) the value of $V_{\odot}$ (-19.5 km) was indifferent to the inclusion or exclusion of the constant error K. This was assumed, therefore, as a basis for intercomparison of the different classes. The individual stars of the six classes were cleared of the solar motion, using the value of -19.5 km for $V_{\odot}$, neglecting K and assuming the position of the apex at $\alpha = 270^{\circ}$, $\delta = +30^{\circ}$. There is perhaps a doubt about the assumption of this apex, but in the absence of any definite knowledge it seems justifiable to use it.

Campbell finds a very consistent tendency of the radial velocities to place the apex about 8° south of that found from the proper motions. He also concludes that the velocities of the stars are greater in the plane of the Milky Way. It seems not improbable that the greater velocities in the Milky Way will be found to explain the difference in the positions of the apex. As soon as the solar velocity and the velocities with respect to the galactic and non-galactic regions become better known and more observations available it should be possible to test the matter more fully.

Groups of all classes of stars were selected with respect to the apex, antapex, and the two regions at right angles to these having distances from the apex between 70° and 110° and being between 22^h and 2^h and between 10^h and 14^h.

The results are given in Table II.

Attention may be called to the peculiar progressions in the group velocities at right angles to the direction of solar motion shown in Table V. These progressions resemble similar ones in the values of the solar motion and constant term K.

[1] *L. O. Bulletin*, No. 196, p. 127.

The number of stars concerned in these groups is not large, and abnormal individual velocities probably affect them to some extent, especially in the stars of the middle and later types.

TABLE II

RESIDUAL VELOCITIES

	Apex		Antapex		22^h–2^h		10^h–14^h	
	No.	Mean V	No.	Mean V	No.	Mean V	No.	Mean V
		km		km		km		km
B..........	22	+2.4	36	+ 6.2	18	+0.7	27	+5.4
A..........	28	+2.1	21	− 2.0	20	+5.0	19	−3.1
F..........	24	−4.2	18	− 2.3	15	+8.0	11	−0.8
G..........	21	+1.3	12	− 7.0	21	+2.6	15	−3.6
K..........	31	−4.3	39	+ 2.6	43	+5.9	28	+2.1
M..........	11	−6.2	12	+ 6.2	16	+2.5	13	+7.3
	10*	−0.2	11*	+11.5	......	....	......	....

* Rejecting one large value.

There is probably also some effect still remaining of any differences between the corrections applied for the solar motion and the true ones; but as the true ones must be considered unknown for the present, we have no other recourse.

The general character of these peculiarities is believed nevertheless to represent real conditions. However this may be, whether due to a single physical cause or only to groups of abnormal velocities, any such conditions will affect the solar-velocity and constant-error terms derived from data containing them.

The peculiar relations between the solar motion and constant errors are exhibited in Table III.

TABLE III

	$V_\odot$	K	$V_\odot + K$	Mean R	$V_\odot$ +Mean R
	km	km	km	km	km
B...........	−20.2	+4.07	−16.1	+4.3	−15.9
A...........	−16.8	+0.95	−15.8	−0.4	−17.2
F...........	−15.8	+0.06	−15.7	−0.3	−16.1
G...........	−16.0	−0.20	−16.2	0.0	−16.0
K...........	−21.2	+2.82	−18.4	+3.5	−17.7
M...........	−22.6	+3.93	−18.4	+5.1	−17.5

Column 5 of Table III contains the mean residual of all of the stars after correction for solar motion on the basis of $V_\odot = -19.5$ and $K = 0$. These are seen to follow closely the value of K found by Campbell and may be considered to be essentially the same quantities.

Campbell concludes[1] that the elements of the solar motion are apparently indifferent to the inclusion or omission of the term K.

That appears to be true so far as the mechanical solution is concerned, but how are we to explain the peculiar relation of $V_\odot$ and this constant term indicated in Table III? Notwithstanding the fact that this constant error was determined along with $V_\odot$ and therefore that $V_\odot$ ought to be free from any such effect, we find the values of $V_\odot$ varying systematically in such a way that the algebraic sum of $V_\odot$ and K (but closer still of mean R and $V_\odot$) is a nearly constant quantity. The conclusion seems justified that, notwithstanding its apparent elimination, at least a part still remains, or that its real significance is other and that an entirely different explanation must be sought.

It is not necessary to give the details of all the tests applied, but the two tables following show the values of the solar motion obtained from hemispheres around the apex and the antapex (Table IV) and for different portions of these hemispheres (Table V) as they came accidentally in the tabulations for solution. No attempt was made to form them into groups according to region of sky, although in a general way this has resulted from taking the stars in the order of right ascension. K was omitted.

TABLE IV

	B		A		F*		G		M	
	No. Stars	$V_\odot$	No. Stars	$V_\odot$	No. Stars	$V_\odot$	No. Stars	$V_\odot$	No. Stars	$V_\odot$
		km		km		km		km		km
Apex.....	90	−11.5	111	−17.4	103	−16.3	63	−17.7	38	− 8.0
Antapex...	133	−27.3	101	−15.2	93	−18.1	74	−18.0	42	−30.1
All.......	223	−21.9	212	−16.4	196	−17.2	137	−17.9	80	−20.1

* One star of very large velocity was omitted in Class F. In Class G all stars having velocities of 50 km and over were omitted, as the solar velocities from all stars were abnormal, −34.6 km from the apical region and −37.1 km from the antapical region. The effect was traced to the fact that practically all of the great velocities were negative in the apical and positive in the antapical regions. Here we have unequivocal evidence of the possible effect of systematic velocities on the solar motion.

[1] *L. O. Bulletin*, No. 196, p. 127.

The foregoing results seem to me to point to the necessity of looking for other effects as well as for constant error depending only on spectral class, probable as such an error seems.

TABLE V

	B		A		F	
	No. Stars	$V_\odot$	No. Stars	$V_\odot$	No. Stars	$V_\odot$
		km		km		km
Apex........	45	−15.8	44	−14.4	50	−18.5
	46	−22.3	43	−18.2	53	−16.1
	....	....	24	−13.1	....	....
Antapex.....	42	−18.9	44	−19.7	50	−15.0
	44	−23.1	43	−12.4	45	−20.0
	48	−17.6	14	−15.3	....	....

The explanation for this constant error has for its basis a physical cause which should produce a nearly uniform effect among the stars of the same spectral class, whereas we find large discordances among groups of such stars in different regions of sky.

The range of about six kilometers which exists between the velocity of the solar motion derived from the different spectral classes seems entirely too large to be explained by *accidental* errors or velocities alone.

CONCLUSIONS

1. The values of the solar motion derived from the different spectral classes separately show large and systematic variations.

2. The values of the solar motion, the residual motions, and the mean velocities show wide variations in different regions of the sky and within the same spectral class.

3. The constant error, and the solar motion, derived from each spectral class, vary in such a way that the algebraic sums of these two quantities are in very good agreement. This gives rise to the suspicion that these quantities are still related.

4. Discordances appear to be too great to be represented wholly by the assumption of a mere constant error within any spectral class.

5. It is believed that the chief cause of the discordances noted is to be found in systematic or semi-systematic motions of the stars and that until some degree of success has been obtained in the determination and elimination of such motions the true value of the solar motion must be considered to be uncertain.

It is yet to be seen whether the star streams already known are competent to account for the peculiarities observed. The peculiarities observed indicate that at least some modifications will be required.

Since the above was prepared I have been able to represent the observed radial velocities of the stars of Classes A and B better upon the assumption of general preferential motions of the stars themselves. The resulting values of the velocity of the solar system are much better harmonized also by such an assumption. It was found necessary, however, to limit the stars used to those in and near to the Milky Way.

The assumed vertex of preferential stellar motions was right ascension 0^h and declination $+60°$. Preliminary solutions based upon this vertex and apex of the solar motion at 18^h, $+30°$ yield the following results:

	Class B	Class A
	km	km
$V_\odot$	-19.4	-19.4
V_s	-1.8	$+9.1$
K	$+4.3$	0.0

The residuals for the solutions, including the V_s term and omitting it, are as follows:

	Including V_s Term $\frac{[vv]}{100}$	Omitting V_s Term $\frac{[vv]}{100}$	No. of Groups in Solution
Class B	56	139	6
Class A	39	510	8

The improvement in the case of the stars of Class B is not so marked as in the stars of Class A. This is perhaps to be expected

from the smaller value found for the preferential stellar velocity in the former case.

These solutions can only be considered as approximate. Whether a larger number of stars would confirm the results obtained and whether all of the spectral classes will show similar peculiarities may be questioned, of course. There is reason to believe, however, that some such preferential general motions will be found to be real, although their magnitudes and characteristics may be considerably altered.

The value of the solar motion from the new solutions appears to confirm that derived by Campbell from all of the classes together.

The numerical value of the *K* term for stars of Class B remains practically unchanged.

There are strong indications here also that the B8 and B9 stars should be grouped apart from the earlier stars of Class B.

Observatorio Nacional Argentino
Córdoba
May 25, 1915

THE ORBITAL ELEMENTS OF THE ECLIPSING VARIABLE SX DRACONIS

By W. VAN B. ROBERTS

The observations used were those published in the *Annales de l'Observatoire Royal de Belgique*, **13**, II, 1914, and the *Publications of the Vassar College Observatory*, No. 3.

After an approximate period from Belgian observations had been obtained and a rough light-curve plotted, this curve was applied to the observations on various nights to get the best value of the time when the star was of the eleventh magnitude, or fifteen "degrés" on the Belgian scale. Several of the Belgian comparison stars were identified with the Vassar comparison stars for which the magnitudes on the Harvard scale were given. By means of these stars and by comparing the magnitude of the variable when at constant light in the two systems, the following formula was found for converting degrés to magnitudes:

$$\text{mag.} = 11.7 - 0.0914(d - 5.8)$$

The period finally determined from the combined Belgian and Vassar observations was 5.16935 days and the epoch of middle of minimum determined from the mean curve was J.D. 2418683.409.

Observations of nearly equal phase were then combined into normals, then normals of nearly equal phase before and after the middle of minimum were combined, giving a table of "super-normals" which was used to draw the light-curve.

Using this curve and following the method, due to Professor H. N. Russell,[1] it was found that the assumption of a total eclipse of a bright spherical star by a larger and fainter companion, both showing disks of uniform brightness, would reproduce the observed variations in light, provided we have the following relations:

Light of bright star = 0.862 of the total light.
Radius of bright star = 0.137 of the radius of orbit.
Radius of faint star = 0.360 of the radius of orbit.
Inclination of orbit plane = $78°09'$

[1] *Astrophysical Journal*, **35**, 315, 1912; **36**, 54, 239, and 385, 1912.

for, on calculating the light-curve of such a system, it was found to coincide within the limits of error with that obtained from the Belgian observations.

On the other hand, if we assume a system like the foregoing in nature, with the exception that in the new system the stars show disks completely darkened at the limb, it would also reproduce the observations, provided that

The radius of bright star $=0.1957$ of the radius of the orbit.
The radius of faint star $=0.321$ of the radius of the orbit.
The inclination of orbit $=84^\circ 45' 25''$.

Since either of these two hypothetical systems would account equally well for the observations, we are in doubt as to the real nature of the true system. The second hypothesis, however, seems the more likely considering the evidence of the sun, which is darkened at the limb.

The observations made at Vassar seemed from the magnitude of the residuals to be affected by large accidental errors and yielded a curve that could not be represented by the eclipse hypothesis.

If we assume the masses of the two components equal, the formula, density $=0.00672\,P^{-2}\,r^{-3}$, gives for the uniform case a density of the larger star $=0.0054$ and of the smaller $=0.098$, while for the darkened stars we get densities 0.0076 and 0.0335. It is shown by Harlow Shapley in *Contributions from the Princeton University Observatory*, No. 3, that in such a system as this it is probable that the brighter star is also the more massive. Using his equation for the probable mass of the brighter star, knowing what proportion of the total light of the system the bright star gives, we find that we must change the densities in the darkened solution to 0.00433 and 0.0478.

By a method described by Russell and Shapley[1] we may make an estimate of the probable distance of the star, known as the hypothetical parallax. The variable has a spectrum of type A, and by means of its spectral type, density, and our assumptions as to its mass and surface brightness we can make an estimate of its absolute magnitude. Comparing this with the observed magnitude we find

[1] *Astrophysical Journal*, **40**, 417, 1914.

the parallax is $0''.00087$, which means that the star is 3750 light-years away. Its galactic latitude is $+26°$, so that its distance from the galactic plane is 1650 light-years, which is one of the greatest known distances of a variable star from the galactic plane.

Table I gives the normals, supernormals, and residuals.

TABLE I

RESIDUALS FOR DARKENED SOLUTION AND UNIFORM SOLUTION

Normals				Supernormals			
Phase (in Days)	Degrés	O−C (Darkened)	Uniform	Phase	Degrés	O−C (Darkened)	Uniform
−0.326	24.9	$-0^{M}.21$	$-0^{M}.23$	0.043	5.7	$-0^{M}.01$	$-0^{M}.01$
.280	23.2	− .15	− .17	.078	6.7	+ .004	− .006
.262	22.3	− .14	− .15	.107	8.8	− .01	− .03
.212	20.4	+ .04	+ .04	.130	10.9	− .004	− .01
.176	18.2	+ .18	+ .18	.149	12.0	− .01	− .01
.166	15.8	+ .05	+ .05	.169	14.9	− .04	− .04
.153	13.3	− .02	− .02	.181	17.9	+ .09	+ .09
.137	11.3	− .04	− .04	.208	20.1	+ .03	+ .03
.123	10.4	+ .03	+ .02	.239	22.1	− .02	− .03
.107	10.0	− .01	− .03	.262	23.2	− .05	− .06
.102	8.1	+ .03	+ .01	.283	25.0	− .01	− .03
.078	6.9	+ .08	+ .07	0.325	26.9	−0.03	−0.05
− .038	5.3	− .04	− .04				
+ .002	6.6	+ .07	+ .07				
.045	6.5	+ .06	+ .06				
.074	4.0	− .08	− .09				
.076	6.9	+ .09	+ .08				
.111	6.7	− .16	− .17				
.140	10.1	− .17	− .17				
.148	12.2	− .07	− .07				
.172	14.0	− .16	− .16				
.185	17.6	+ .03	+ .03				
.203	19.9	+ .05	+ .05				
.230	21.8	− .01	− .02				
.251	23.0	− .01	− .02				
.262	24.6	+ .06	+ .05				
.280	25.7	+ .07	+ .05				
.295	27.0	+ .12	+ .11				
.315	28.5	+ .15	+ .13				
+0.344	30.1	+0.20	+0.18				

The foregoing computations were made with the kind assistance and supervision of Professor H. N. Russell throughout.

PRINCETON UNIVERSITY OBSERVATORY
June 2, 1915

ORBITAL ELEMENTS OF THE ECLIPSING VARIABLES TW ANDROMEDAE, TU HERCULIS, AND RS VULPECULAE

By JOHN Q. STEWART

The right ascensions and declinations of these stars for the year 1900 are:

TW Andromedae:	$23^h53^m.1$	$+32°17'.3$
TU Herculis:	17 9.8	+30 50.0
RS Vulpeculae:	19 13.4	+22 16

The light-curves of TW Andromedae and TU Herculis were derived from the eye-estimates of L. Casteels and the photometric observations of G. Van Biesbroeck.[1] Only eye-estimates were available for TU Herculis. These were made by the Argelander method; the brightness of the variable is stated not in magnitudes but in "degrés." The brightness of some of the comparison stars of TW Andromedae is given in photometric magnitudes as well. A consideration of these stars showed that the relation between degrés and magnitudes is approximately linear: 1 degré=0.095 magnitude. The following transformation equations were found to hold:

For TW Andromedae, 0.095 (degrés$-$2.2)$=$10.76$-$mag.
For TU Herculis, 0.095 (degrés$-$2.0)$=$11.70$-$mag.

The phases of the observations (which are not published in the Belgian *Annales*) were calculated; and observations of nearly equal phase were grouped into normals. These are given below. In the case of TW Andromedae the photometric observations were assigned double weight. It was found unnecessary to change Van Biesbroeck's periods, but for each star it seemed advisable to shift his epoch of middle of minimum. This correction, for TW Andromedae, amounted to $-0^d.007$, for TU Herculis it was $+0^d.006$. The corrected values are:

TW Andromedae: J.D. $2418629^d.267+4^d.1229$ E.
TU Herculis: J.D. $2418831^d.440+2^d.26713$ E.

[1] *Annales de l'Observatoire Royal de Belgique*, 13, II, 1914.

The solution of TW Andromedae presented no difficulty. The maximum brightness is well determined by fifty visual observations. There appears to be no sensible secondary minimum. At the middle of the primary minimum there is a distinct, constant, total phase. Application of the methods of Professor Henry Norris Russell showed that the observed light-curve could be fitted very well on either the "uniform" or the "darkened" hypothesis.[1]

TABLE I

TW ANDROMEDAE—NORMALS

PHASE*	NO. OBS.†		OBS. MAG.	O−C
	P	E		
				mag.
$-0^{d}.173$	3	5	9.27	+0.01
.149	3	5	9.46	.00
.130	2	5	9.67	− .02
.108	0	4	9.92	.00
.091	4	4	10.14	+ .03
.066	4	4	10.45	+ .04
.058	0	4	10.66	− .02
.047	0	5	10.73	− .01
.039	4	0	10.72	+ .04
.021	0	15	10.78	− .02
.002	5	0	10.77	− .01
+ .019	0	18	10.75	+ .01
.044	3	0	10.81	− .06
.044	0	5	10.77	− .02
.052	0	4	10.70	.00
.063	3	7	10.56	.00
.083	3	7	10.28	.00
.104	3	9	9.98	+ .01
.132	3	4	9.65	− .02
0.166	5	5	9.40	+0.02

* The phases given are corrected to the revised epoch of middle of minimum.

† P indicates photometric, E, eye-estimates.

All the residuals in each case are so small that it seemed only worth while to publish the calculated "darkened" curve. There is nothing especially remarkable about this star, except the large color-index noticed by Harlow Shapley at Mount Wilson.[2] He finds a photo-visual range of 1.63 mag. and a photographic range of 2.04 mag.; the brighter component he gives as type F3, and the fainter as G4.

[1] See preceding paper by W. Van B. Roberts for references.

[2] *Publications of the Astronomical Society of the Pacific*, **26**, 156, 1914.

The light-curve of TU Herculis heretofore always has been drawn with a flat-bottomed minimum—indicative of total (or annular) eclipse. The orbital elements derived from such a curve, however, show that the eclipse is just partial. Nevertheless it comes so near totality that the method of solution for a totally eclipsing variable suffices to give the elements with quite satisfactory accuracy. The round-bottomed minimum necessitated by the partial eclipse represents the observations as well as, or

TABLE II

TU Herculis—Normals

Phases	No. Obs.	Obs. Mag.	O−C
			mag.
$-0^{d}136$	5	9.75	−0.14
.063	5	10.49	+ .10
.033	5	11.35	.00
.016	2	11.69	− .01
.008	1	11.59	+ .08
+ .007	2	11.69	− .02
.022	3	11.50	+ .04
.045	5	11.06	.00
.062	5	10.65	− .01
.082	5	10.28	− .06
.091	5	10.03	+ .05
.100	5	9.94	+ .01
.111	5	9.78	+ .04
.127	5	9.67	+ .02
0.141	3	9.60	−0.02

* Phases corrected to new epoch of middle of minimum.

better than, the flat one. The maximum percentage area of the smaller star obscured by the larger (α_0) is 0.998 by the "uniform" solution and 0.995 by the "darkened."

The constant maximum brightness of the variable is determined by thirty-six closely agreeing eye-estimates. Its value in magnitudes is somewhat uncertain, but was assumed to be 9.50 mag. This uncertainty does not in the least affect the accuracy of the solution, which depends only upon the range in brightness. None of the observations are of the proper phase to give information concerning the existence of a secondary minimum. The spectrum of TU Herculis is unknown; the hypothetical parallax was calculated on the assumption that it is of type A. Both

the "darkened" and the "uniform" curves closely represent the observations; only the "darkened" residuals are published.

For RS Vulpeculae, the final variable considered in this paper, the visual observations of Mentore Maggini were used.[1] His brightnesses are in magnitudes, corrected to the Potsdam scale. Before drawing the light-curve, the thirty-three normals given by him (each of which represents five observations) were combined into supernormals. The epoch of middle of minimum is not

TABLE III

RS VULPECULAE—SUPERNORMALS

Phase*	No. Normals	Obs. Mag.	O−C
			mag.
$-0^d.401$	5	7.30	0.00
.280	3	7.41	+ .02
.244	1	7.53	.00
.215	2	7.67	+ .02
.178	3	7.82	− .01
.135	4	7.97	− .02
.101	2	8.07	.00
+ .006	5	8.11	.00
.112	2	8.04	− .01
.163	1	7.87	− .02
.229	4	7.60	.00
0.286	1	7.32	−0.05

* A correction of $-0^d.097$ was applied to Maggini's phases.

well determined, on account of the scarcity of observations during increasing light. Assuming Maggini's period, it comes at

$$\text{J.D. } 2419652^d.963 + 4^d.477325 \text{ E.}$$

A long period of total eclipse is indicated. It was found necessary to use a special method in solving for the elements. The usual process, when applied to some parts of the light-curve, led to a negative radius for the smaller star, and, for other parts, made it appear that the smaller star was the larger of the two. By the use of the following simple method, however, all difficulties were eliminated, and a light-curve was calculated which satisfies all of the observations. The light-curve gives $\sin^2\theta$ as a function of α (following Professor Russell's notation). But we know that $\sin^2\theta$ is a linear function of $\psi(k,\alpha)$. When $\sin^2\theta$, taken from the

[1] *Astronomische Nachrichten*, **200**, 54, 1915.

light-curve for various values of α, was plotted as ordinate against the corresponding values of $\psi(k,\alpha)$ as abscissae for different arbitrarily chosen values of k, it was found that a straight line passed through all the points k = constant only for $k = 0.20$. This same value of k was found in both solutions ("uniform" and

TABLE IV

TABLE OF ELEMENTS

	TW ANDROMEDAE		TU HERCULIS		RS VULPECULAE	
	mag.		mag.		mag.	
Maximum	8.99		9.50		7.30	
Depth of primary	1.77		2.19		0.81	
	"Uniform"	"Darkened"	"Uniform"	"Darkened"	"Uniform"	"Darkened"
	mag.	mag.	mag.	mag.	mag.	mag.
Depth of secondary	0.044	0.10	0.036	0.070	0.021	0.021
Semi-duration of entire eclipse	5^h47^m	6^h12^m	4^h9^m	3^h48^m	8^h2^m	8^h2^m
Semi-duration of total eclipse	0^h58^m	0^h52^m	....	....	1^h49^m	0^h58^m
Light of brighter star (L_b)	0.804		0.866		0.526	
Radius of brighter star (r_b)	0.124	0.155	0.146	0.189	0.090	0.0932
Radius of fainter star (r_f)	0.248	0.232	0.299	0.278	0.450	0.466
Cosine of inclination (cos i)	0.107	0.054	0.155	0.098	0.346	0.368
Ratio of surface brightnesses $\frac{J_b}{J_f}$	16.4	9.1	26.9	14	27.7	27.7
Density of bright star* ($\bar{\rho}_b$)	0.29	0.15	0.61	0.28	0.47	0.43
Density of faint star (ρ_f)	0.016	0.020	0.027	0.032	0.0036	0.0032
Radii in term of sun $\bar{r}_b$	1.69	2.11	1.34	1.73	1.30	1.34
$\bar{r}_f$	3.38	3.16	2.73	2.54	6.50	6.70
Spectrum	A		A:		A	
1000 π''	2".0	1".6	2".0	1".1	9".1	9".1
Galactic latitude (β)	$-29°$		$+33°$		$+4°$	
$r \sin \beta$	....	-1000	....	$+1600$	....	$+25$
$r \cos \beta$ (in light-years)	....	1800	....	2500	....	360

* The densities are corrected for brightness (see preceding paper by W. Van B. Roberts).

"darkened"). The slope of the straight line was taken as B, and the intercept on the axis of $\sin^2\theta$ as A. The trouble with the ordinary method of solution in this case was that the two points on the light-curve taken as standard in constructing the tables of $\psi(k,\alpha)$ were nowhere near their correct position.

The value of k (the ratio of the radii of the two components) found for RS Vulpeculae is the lowest yet discovered in an eclipsing

system. This star is further remarkable in being among the nearer eclipsing binaries (if the computed hypothetical parallax is to be trusted). In addition, the star is a bright one, and the period of total eclipse long, so that the color-index of each component could easily be determined. Further observations would certainly be valuable and might be of the greatest theoretical interest. The elements deduced here doubtless are not altogether accurate; they are far from agreeing with those calculated by Shapley[1] from the light-curve of Professor Nijland.

I take much pleasure here in thanking Professor Russell for his many suggestions, and for the great interest he has taken in these calculations.

PRINCETON, N.J.
June 7, 1915

[1] *Contributions from the Princeton Observatory*, No. 3.

AN ADAPTATION OF THE KOCH REGISTERING MICROPHOTOMETER TO THE MEASUREMENT OF THE SHARPNESS OF PHOTOGRAPHIC IMAGES[1]

By ORIN TUGMAN

A photometer for measuring the brightnesses of small areas has been desired for some time in the study of the intensities of spectral lines and in the investigation of the properties of photographic plates. The Hartmann microphotometer has served this purpose. But the most recent apparatus of this kind is the Koch[2] registering microphotometer, which eliminates visual observation by registering on a photographic plate the readings of the instrument. This paper gives an account of the adaptation of this apparatus to the measurement of the sharpness of photographic images and a statement of the limitations and necessary corrections which have been found in using Koch's photometer in the investigation of photographic resolving power.

The Koch registering microphotometer was originally designed to measure the densities of the developed photographic images of spectral lines, but as the apparatus was used by Koch, and by King and Koch,[3] no attention was given to the resolving power of the apparatus. In many cases inattention to this point will lead to incorrect conclusions drawn from the shape of the registered curve. This apparatus has been adequately described in the papers referred to above, but a brief description here may not be out of place.

The developed negative is passed under an illuminated slit over which is an objective of a microscope which carries a second slit in the focal plane of the objective as shown in Fig. 1. The current generated by the incident light in the photo-electric cell C charges the silvered quartz fiber Q of a string electrometer. The movements of the quartz fiber are registered on a falling photographic plate by throwing an image of the fiber on the photographic plate by means

[1] Communication No. 27 from the Research Laboratory of the Eastman Kodak Company.

[2] *Annalen der Physik*, **39**, 705, 1912. [3] *Astrophysical Journal*, **39**, 213, 1914.

of a microscope and a cylindrical lens. A clockwork moves the original negative under the illuminated slit and simultaneously drops the registering photographic plate at a constant speed. One source of light serves to illuminate cell C_1 and at the same time cell C_2, which affords an adjustable leak to earth for the current charging the quartz fiber.

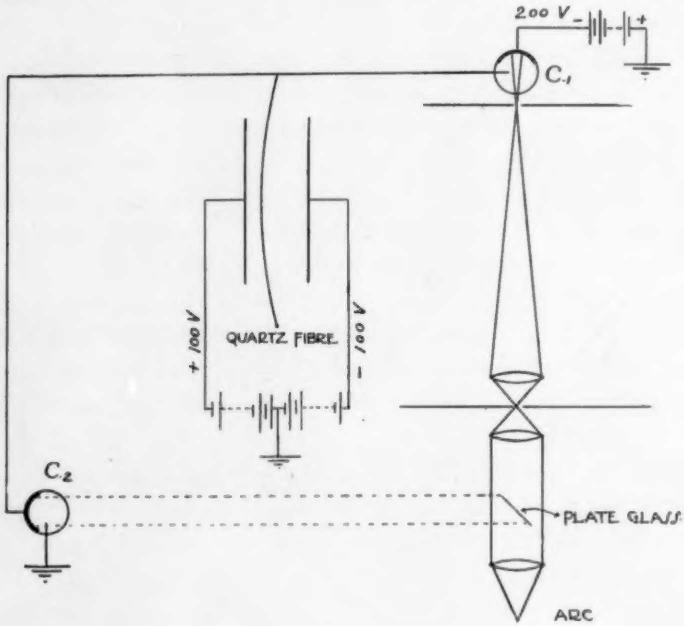


FIG. 1

By assuming that the movement of the quartz fiber is proportional to its potential, an equation is obtained giving the relation between the distance moved and the intensity of the illumination on the photo-electric cells. Under the working conditions of the apparatus it is assumed that the current through a photo-electric cell is proportional to the intensity of the illumination on the photo-electric surface and the difference of potential between that surface and the sealed-in electrode. This is in accord with known facts.

Let V_1, V_2, and V be the potentials of cell 1, cell 2, and the quartz fiber respectively, and let L_1 and L_2 be the respective illuminations

on the cells 1 and 2. In a state of equilibrium the current through cell 1 is equal to the current through cell 2. Therefore, we may write

$$K_1L_1(V+V_1)=K_2L_2(C-V_2),$$

where K_1 and K_2 are constants. It is seen that when L_1 is zero the potential of the fiber V is V_2, which is the potential acquired by the photo-electric surface when illuminated.

The relation between the distance x moved through by the quartz fiber and the potential V was determined experimentally by

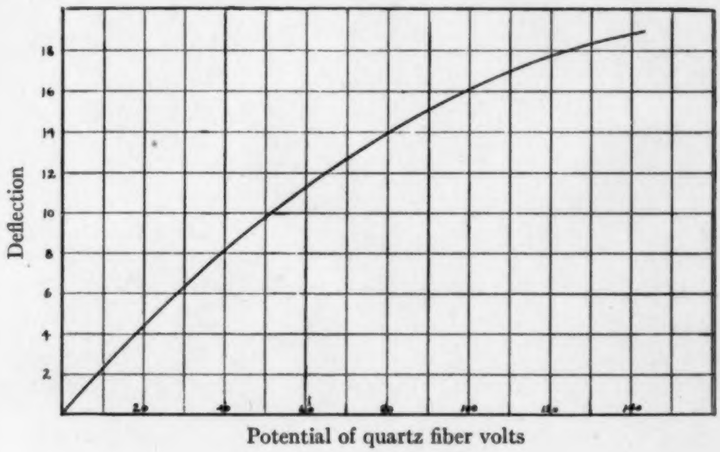


FIG. 2

illuminating cell C_2 and applying different potentials to the quartz fiber. This relation is shown graphically in Fig. 2. Obviously, there is not a linear relation between the movement of the quartz fiber and the intensity of the illumination on the cell C.

The use to which the Koch registering microphotometer was put in the Research Laboratory of the Eastman Kodak Company was to measure the sharpness of photographic images in an investigation of resolving power of photographic plates. A carefully ground knife-edge was placed on a photographic plate and the whole exposed to a beam of parallel light. The developed negative was passed through the Koch photometer to obtain a curve giving the falling off in density from the edge of the image.

On an ordinary photographic plate the distance at the edge of such an image between maximum and minimum density is less than 50 μ and in many cases not over 10 μ. It was necessary, therefore, to use a microscope of greater magnifying powers than that supplied with the Koch apparatus. The upper slit of the microscope should not cover more than one-fifth of the total width of the image of the photographic edge. Accordingly, a 4 mm objective was placed in the microscope and the upper slit was adjusted to cover 10 μ of the object. In this arrangement the lower slit under the objective was not used. It was found, however, that the apparatus was not sufficiently sensitive on account of insufficient light on the cell C_1. To overcome this difficulty the Nernst filament was replaced by an arc light, and a microscope condensing lens was placed under the plate carrying the negative. A condensing lens in front of the arc cast a parallel beam on an inclined mirror under the microscope condenser. In this way a powerful beam of light was concentrated on the object. A water cell in front of the arc prevented burning of the emulsion film. A piece of plain glass in the path of the parallel beam reflected sufficient light on the cells C_2 and C_3. With this arrangement the photo-electric cells operated the quartz fiber across its complete range of movement.

After these alterations it was found that the relative motion of the registering photographic plate and the negative under measurement was too small. It was necessary to alter the clock mechanism so the registering plate could have a maximum speed of one thousand times the speed of the plate carrying the negative.

With the apparatus so altered and the slit in the microscope adjusted to cover 10 μ of the object, it was considered necessary to determine the correction due to the width of the slit. This point has not been discussed in the previous papers published on the Koch photometer.

Obviously, the best method of measuring the slit-width correction is to make a record of a sharp knife-edge. A Gillette razor blade fastened by soft wax to a microscope slide was passed under the microscope, care being taken to set the razor edge parallel to the edge of the slit. It is easy to predict the shape of the record under such circumstances. The record should be a straight line

across the plate at an angle depending on the relative speed of the registering plate and the razor edge. If the slit covers 5 μ and the movement of the edge is multiplied one thousand times, one end of the straight line on the record should be displaced just 5 mm farther along the plate than the other end. This should be the result independent of the amplitude of the motion of the quartz fiber. The kind of record actually found is shown in Fig. 3.

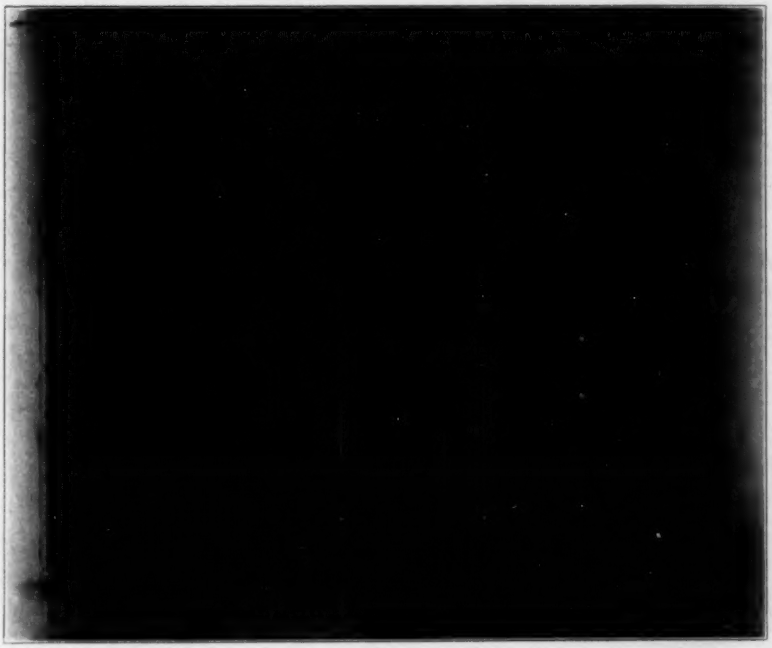


FIG. 3

Under the conditions named above with a 5 μ slit the record made with a razor edge had a slope much greater than calculation would indicate. A record was made with the slit covering 2.5 μ and also covering 10 μ. In all three cases the straight-line slope was constant, when first consideration would indicate that the slope of such a curve should vary inversely as the width of the slit. When the width of the slit covered about 15 μ, the slope of the line began to change as the slit-width increased. Thus, the maximum slope

of the line was such that one end was 0.15 mm farther along the plate than the other.

A search for the cause of these results revealed that a pinhole image was being formed on the photo-electric surface by the slit in the microscope barrel. That this is a fact could be demonstrated by holding a piece of ground glass above the microscope and moving the razor edge under the microscope objective. An image of the razor edge could be seen moving out from both sides of the slit, one evidently being that cast by the objective on the slit, and the other image being that made by the slit on the screen. One might expect this pinhole image of the last surface of the objective to be formed by the slit. Then a decrease in the intensity of the light falling on the photo-electric surface would begin as soon as the razor edge began to pass under the objective and would continue until the objective was entirely covered. But the effect of the pinhole image is small compared to the passing of the objective image across the slit, and it is only when the slit is small that anomalous results appear.

It will be seen that a serious error is introduced if measurements are made on a density-gradient which extends over a distance of only about 30 μ, that is, about twice the width of the slit in the focal plane of the objective. During the time the slit is being covered and until the slit is completely covered, the record cannot be a true register of the density-gradient. Also, when the maximum density of the negative begins to pass, the record is erroneous. It is only when the slit is completely covered by the image that a true record is possible. Moreover, any irregularities of breadth less than 15 μ in the density-slope will be incorrectly registered. The curve for a very fine spectral line would be too narrow at the points of maximum density. If the density-slope is long compared to 15 μ, the error grows less. This applies, however, only to the case where a 4 mm objective is used.

The difficulty mentioned above comes from the absolute value of the slit-width. If the magnification is less, the width of the slit cannot be less in actual measure because of the pinhole image formed. With the 4 mm objective giving a magnification of 50 the actual width of the slit was 0.75 mm, covering 15 μ of the object.

Therefore, with a magnification of 25 the slit would still be 0.75 mm wide and cover 30 μ of the object. The resolving power of the apparatus is limited by the magnification of the microscope objective and not by reducing slit-width to less than 0.75 mm.

As was pointed out above, the top and bottom of a registered curve will be in error over a distance depending on the slit-width d, magnification m, and relative speeds of the registering plate and the negative under measurement. This may be expressed

$$R=\frac{ds}{m}.$$

R is the actual distance parallel to the vertical side of the registering plate, through which the curve is in error.

For a registered curve of a density-gradient extending over narrow limits the corrections are such that their application becomes laborious. In such cases it is doubtful if the record is sufficiently accurate to admit the correction. Consider a slit, Fig. 4*a*, and a wedge passing under, cutting off light from below. Suppose the light transmitted by the wedge is some function $f(x)$ of x, where x is measured from the point of the wedge. The light L_0 passing through the slit is

FIG. 4
a. Slit and wedge .
b. Curve for light-transmission of wedge

$$L_0=\beta(A-x)+\int_0^x f(x)dx.$$

The equation $L_1=\beta(A-x)$ applies for opaque edge passing the slit if light diffracted around the edges is neglected. β= constant.

$$L_0-L=\int_0^x f(x)dx$$

is an equation giving the total light transmitted by the wedge at any position. After reducing the ordinates of the registered curve by $(A-x)$ and plotting another curve, the true light-transmission of the wedge can be obtained by taking the difference of any two

adjacent ordinates and dividing by the difference in abscissae, as shown in Fig. 4*b*.

Calibration of the electrometer scale was made by passing under the microscope, while the registering plate was in motion, a photographic negative bearing a series of densities. The record made was an irregular stair-step trace on the registering plate. Fig. 5 shows a type of the calibration-curve. Obviously, the slope *x* and shape of this curve will be altered by changing the tension of the

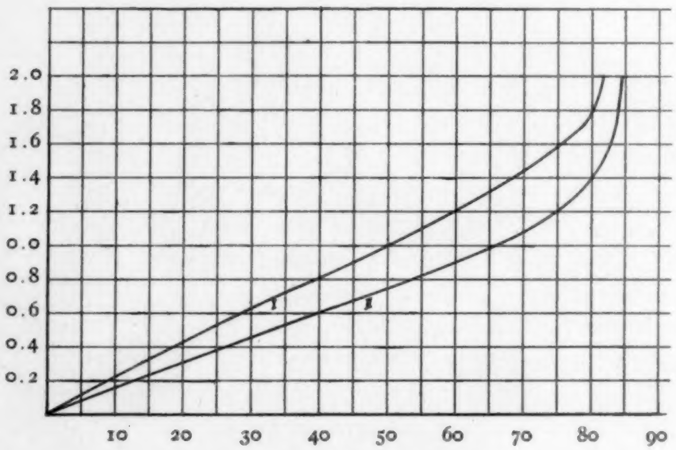


FIG. 5.—Calibration-curve

I. Density measured by spectral transmission
II. Density measured by diffuse transmission

fiber, the adjustment of the electrometer plates, and relative illumination of the photo-electric cells. However that may be, it is most essential to know how the densities used for calibration are measured. It must be remembered that a photographic negative is a light-diffusing medium and the value of the measured density of such a material depends on whether the measurement is made with diffuse or specular light. The beam of light passing through a negative into the microscope of the Koch instrument is practically all due to specular transmission. Furthermore, the percentage of diffusion produced by a negative is a function of the size and number of silver grains in the gelatine layer. It is necessary, therefore,

for correct calibration that the calibrating densities be from the same emulsion as the negative being measured, and also that the densities be measured by specular transmission. The calibration-curves when made from densities measured by diffused and specular light are seen in Fig. 5. There is very nearly a constant ratio between the two curves throughout the entire range, but this constant ratio would not be the same for all kinds of negatives.

The shape of the calibration-curve shows that for high densities the accuracy of measurement is greatly decreased. This feature of the apparatus is a disadvantage in investigating the sharpness of photographic images of high density. Koch claimed in his original paper on this apparatus that the relation between movement of the quartz fiber and the density of the negative was nearly linear within a limited range. The curves here verify that statement.

Measurements on the relative energies of the spectrum lines were made by King and Koch with this registering photometer. The negatives were made with an exposure which did not produce a density too great for the apparatus to register with reasonable accuracy. The area of the curve obtained was taken as a measure of the energy of the line.

The use of photographic plates for recording the distribution of energy of a spectrum line was investigated by Koch.[1] He calibrated the Hartmann microphotometer with a series of densities made with a known series of exposures. A method more in line with the system usually adopted in measuring the light-sensitiveness of photographic plates has been outlined by Mees.[2]

In the system of sensitometry of photographic plates developed by Hurter and Driffield,[3] the density is plotted against logarithm of exposure, and the curve obtained is in general like Fig. 6. Here density is defined by the equation

$$I_1 = I_0(10)^{-D},$$

where I_0 is incident light on the negative and I_1 is transmitted light. With different periods of development the straight part of the curve will swing about a point on the axis of log E indicated by producing

[1] *Annalen der Physik*, 30, 84, 1909.

[2] *Knowledge*, 33, 417, 1910.

[3] *Jour. of Soc. of Chem. Industry*, May 1890.

the straight line until it cuts the axis of log E. The slope of this straight portion increases with development up to a maximum value depending on the character of the emulsion. The maximum slope for any plate is different for different wave-lengths of light. Moreover, the other points of the curve will have a shape depending on wave-length of exposing light.

After the ordinates of the registered curve of the Koch microphotometer have been reduced to densities, the exposure required to produce these densities can be determined from a sensitiveness-curve such as is shown in Fig. 6. This can be done only if the sensitiveness-curve and the original negative are made from the same kind of plate exposed to the same monochromatic light and developed in the same developer for equal periods. Inasmuch as the maximum density which can be correctly registered by the Koch instrument is not much over 1.5, an important part of the exposure must be down on the toe of the curve and off the straight part. This destroys the complete linear relation between the deflection of the electrometer fiber and the logarithm of exposure. The area of the curve made by the Koch instrument cannot, therefore, be a measure of the energy of the spectral line. However, within the straight part of the sensitiveness-curve and also within the straight part of the calibration-curve of the Koch photometer the deflections of the electrometer fiber are proportional to the logarithm of the intensity.

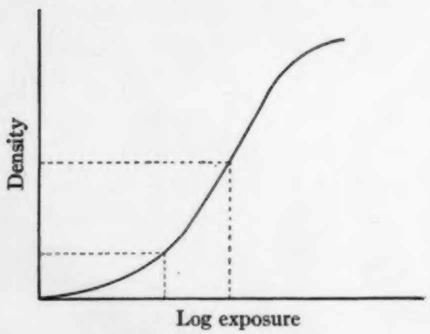


Fig. 6.—Sensitiveness-curve

From the foregoing paragraphs it is seen that this registering microphotometer is a useful instrument only for certain classes of work where the corrections do not apply. It is hoped that the foregoing account will be of service to others interested in microphotometry and in the properties of photographic plates.

Research Laboratory, Kodak Park
Rochester, N.Y.
July 16, 1915

THE RESOLVING POWER OF PHOTOGRAPHIC PLATES[1]

BY ORIN TUGMAN

The resolving power of photographic plates has hitherto been investigated by methods which have been suggested by general definitions. The distance between two closely adjacent images when developed being a measure of resolving power, it has been considered sufficient for a practical test to photograph the reduced image, formed by a highly corrected lens, of some fine-lined structure and determine what lines are resolved. For this purpose Mees has devised a fan-shaped test-object having alternate black and white sectors of about ten degrees in angle. The photograph of the reduced image is examined with a microscope to determine the resolution. In this test the accuracy of the measurement rests upon personal judgment of the separation of two lines.

From theoretical considerations Wadsworth[2] arrived at the conclusion that two lines can be resolved if the distance between their centers is four times the diameter of a silver grain in the emulsion. It is evident that Wadsworth did not take account of the lateral spreading of the light in the emulsion and of the raggedness due to the random distribution of the silver grains. As a result the statement applies only to a non-diffusing medium whose light-sensitive material is in the form of discrete particles distributed at random. But such a non-diffusing medium does not exist.

Wadsworth's theory and the scattering of light by different emulsions has been investigated by Mees.[3] The resolution of the plate was measured by photographing the reduced image of a black and white line grating and examining the plate to determine what lines were resolved. The scattering of the light at different exposures was shown by photographing an illuminated slit covered with a black wedge which admitted light varying in intensity from one to sixty along the length of the slit. The image of the slit was

[1] Communication No. 28 from the Research Laboratory of the Eastman Kodak Company.

[2] *Astrophysical Journal*, **3**, 188, 1896. [3] *Proc. Roy. Soc.*, **83** A, 10, 1909.

reduced about twenty-two diameters. At that end of the image which received the most light there is the greatest amount of spreading. This makes the developed image of the form of a tadpole. The conclusions drawn by Mees are: "The resolution of a photographic plate is dependent upon the amount of irradiation displayed by that plate. The irradiation is not directly proportional to size of grain, but is caused by two different forms of scatter arising from reflection and diffraction. The resolving power is likely to be much smaller than that indicated by the theory of Wadsworth."

The rate of spreading of a photographic image has been investigated by Scheiner,[1] who showed that the increase of the size of an image increased as the logarithm of the exposure. Later, Mees[2] obtained similar results. The reduced image of an illuminated pinhole was photographed and measured. This general method has been followed by Goldberg,[3] who made contact prints through conical holes in a metal plate. The holes were made and arranged so as to insure good contact with the emulsion surface.

Goldberg represented his measurements by a set of curves, reproduced here for discussion (Fig. 1). The increase in diameter of the circular image is plotted against the exposure measured in threshold units. The curve so obtained is called the turbidity-curve and the slope at any point the turbidity-factor. The experiments demonstrated that the turbidity-curve is not dependent on development or size of the opening through which the print is made but is dependent on the physical characteristics of the plate.

It is seen that the slope of the curves changes with exposure, indicating that the turbidity-factor increases with exposure. However, the slope is not consistent with the relation between spreading of the image and exposure found by Scheiner and Mees. A few readings upon the curves will show that the increase in diameter is not proportional to the logarithm of exposure. The increase in diameter plotted against log exposure is not a straight line, as it should be if the logarithmic law is true for a wide range.

[1] *Photographie der Gestirne*, Leipzig, 1897.

[2] *Astrophysical Journal*, **33**, 81, 1911.

[3] *The Photographic Journal*, November 1912.

Goldberg's results are in accord with those of previous investigators, in that he finds the spreading of the image does not depend on the size of the grain of the plate. However, he finds that a grainless Lippmann plate shows no measurable increase whatever of the

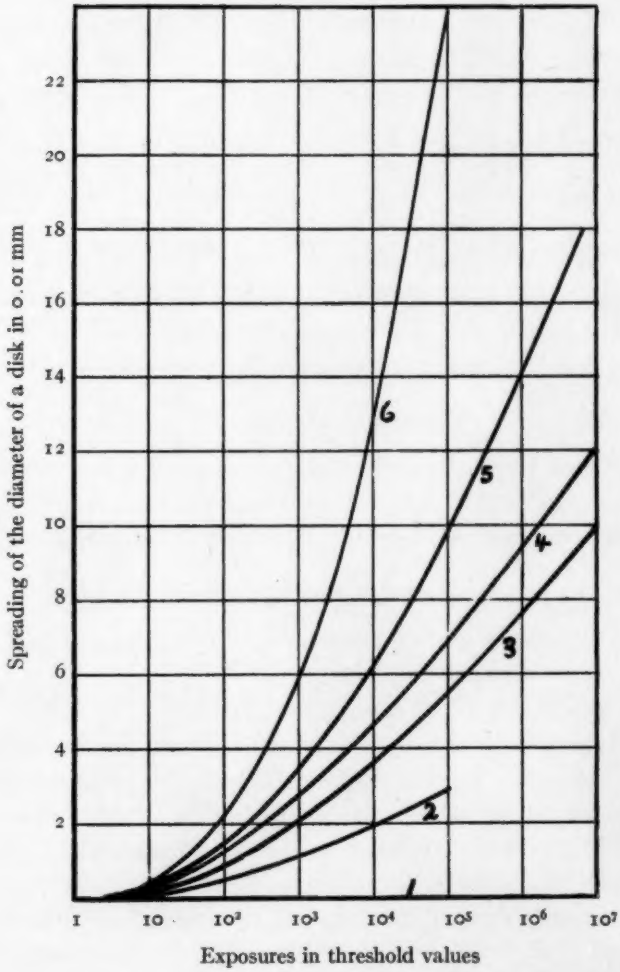


FIG. 1.—Drawn from Goldberg's curves (*The Photographic Journal*, **36**, 1912)

1. Lippmann plate
2. Transparency plate
3. Sigurd moment-plate
4. Portrait plate
5. Double-coated plate
6. Bromide paper

diameter, while the coarse-grained, highly sensitive portrait-plate exhibits strong spreading. But the very fine-grained bromide paper and the high-resolution plate of Wratten and Wainwright, chemically developed, spread the imprinted disk very greatly indeed.

The turbidity-factor was identified by Goldberg with the reciprocal of the light-gradient measured laterally from the image. Let x be the distance of any point a short distance from the edge of the disk and I the intensity of the light. Then, δ is defined $\delta=\frac{-dx}{d(\log I)}$ by differential calculus. If D is photographic density, then the photographic factor $\gamma=\frac{dD}{d(\log I)}$, which is the slope of the curve of sensitiveness obtained by plotting densities against log exposure. The factor of sharpness S is defined as the slope of the curve made by plotting density against distance out from the edge of the image, and that $S=\frac{-dD}{dx}$. Therefore, he has $S=\frac{\gamma}{\delta}$. "In words, the sharpness-factor is equal to the development-factor divided by the turbidity-factor."

Now the question arises: Is Goldberg's turbidity-factor as defined by $\frac{-dx}{d(\log I)}$ the same as the slope of his turbidity-curve? A little consideration will show these two definitions to be inconsistent. In general, when $\frac{dx}{d(\log I)}$, the reciprocal of the light-gradient, is large, the rate of spreading will be large for plates of equal sensitiveness. But the light-gradient cannot be a function of the time of exposure, as is indicated by one of the two definitions of the turbidity-factor. When the exposure begins, the light distributes itself through the emulsion in all directions in a manner depending on the physical structure of the emulsion. During the exposure this distribution of light must remain unchanged. So far as we know the exposed grains do not reflect or scatter any more or less light than unexposed grains. Therefore, there is no reason to argue that the turbidity-factor as defined by $\frac{dx}{d(\log I)}$

changes with exposure. In fact, the slope of Goldberg's turbidity-curve and the factor $\frac{dx}{d(\log I)}$ are not identical.

According to Goldberg's statement the edge of the enlarged disk is not sharp, and there is a gradual shading off of density. This makes the determination of the diameter a matter of difficulty. If, however, one measures out to a constant density on all the images the rate of spreading could be measured. Now, suppose this is done. Let us write the function $f(x)$ giving the relation between $\log I$ and distance x from the edge of the opening

$$\log I = f(x). \tag{1}$$

Our relation between density D and exposure for the straight part of the Hurter and Driffield sensitiveness-curve is

$$D = \log I + B. \tag{2}$$

We can therefore write

$$D = f(x)t + B = \text{Constant}. \tag{3}$$

If we measure out along the diameter to the same density in all the images on the same kind of plate and plot a curve between exposure and x, the slope of the curve is given by differentiating x with respect to t in (3)

$$\frac{dx}{dt} = -\frac{f(x)dx}{df(x)t},$$

which is the slope of Goldberg's turbidity-curve.

It is obvious, therefore, that Goldberg's method of measuring the spreading of an image does not give a measure of the light-gradient.

Besides the discrepancy between Goldberg's theory and results there are objections to the circular aperture used by him. With a small circular hole the light is spreading out radially, and consequently the spreading of the image is not under the conditions which would be imposed by a straight-edge. However, the use of a circular aperture would impose the conditions experienced in photographing stellar images, but would not compare with conditions in photographing fine-lined structures. Moreover, reflection of light from the sides of the conical opening in the metal plate would be a

source of error. The image of a straight-edge would represent more general corrections, but with the disadvantage of not permitting the exact location of the edge on the image.

The use of a straight-edge in investigating resolving power of photographic plates has been described by Nutting.[1] He found that by carefully cleaning and setting a steel blade on the surface of an emulsion all traces of diffraction under the edge could be eliminated. The photographic images obtained were examined under a microscope and the density-gradient plotted. For densities less than unity there was a raggedness of the edge due to the random distribution of the silver grains. The shading off became more apparent with densities greater than 1, and at about a density of 2 the density-gradient appeared to reach a fixed value. In general, the density-gradient increased with decrease of the size of the silver grains. In cases where this rule did not apply, that is, with fine-grained emulsions and least diffusing, yet showing low density-gradients, the photographic gradient was also low. Those plates having a long, low slope in the sensitiveness-curve made by plotting density against log of exposure show a low density-gradient. Nutting pointed out that density-gradient can be written

$$\frac{dD}{dx} = \frac{dD}{d(\log E)} \quad \frac{d(\log E)}{dx}$$

by simple differentiation, where E is exposure.

Inasmuch as $\frac{d(\log E)}{dx}$ is independent of development and $\frac{dD}{d(\log E)}$ is the slope of the Hurter and Driffield sensitiveness-curve, which becomes steeper with development, it was argued that density-gradient should increase with development at the same rate as $\frac{dD}{d(\log I)}$. The experimental work described in this paper was a measurement of the density-gradient for the purpose of determining, if possible, the relation between the other factors of the equation.

The straight-edge used for the photographic images was made by cutting a secant strip from a nickel cylinder and carefully grind-

[1] *Photographic Journal*, June 1914.

ing the edges. A cross-section of the metal strip is shown in Fig. 2, *a*. This edge was placed on a strip of plate about one inch wide and the plate exposed to a parallel beam of monochromatic light. After exposure the plate was cut in two strips and each part developed for a different time. It may be noted here that all plates were well backed before exposure.

The Koch registering microphotometer was used to measure the density-gradient as described in the paper on that instrument published in this *Journal*.[1] The difficulties encountered were such as to necessitate the use of some other apparatus.

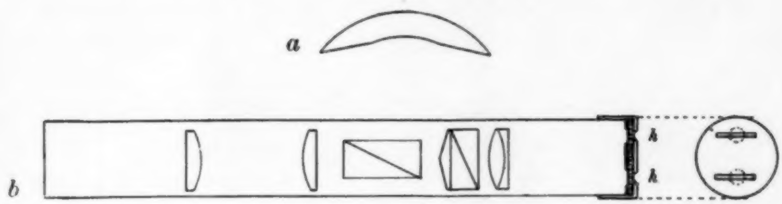


FIG. 2

a. Cross-section of metal strip
b. Polarization photometer

On account of the number and uncertainty of the corrections which are necessary to the curve registered by the Koch microphotometer it was considered necessary to seek for other means of measuring the density-gradient. For this purpose a König-Martens polarization photometer was adapted. A sketch of this apparatus is shown in Fig. 2, *b*. This instrument was used to measure the image of the photographic edge thrown by a microscope on a piece of flashed opal glass placed over the holes *h, h*. On the opal glass on the side next to the microscope was a metal screen having two small parallel slits. Each slit passes over a diameter of one of the holes *h, h*. The photometer was mounted on a carriage which could be shifted by means of a micrometer screw in a plane at right angles to the axis of the microscope. The magnification was adjusted to suit the case by changing the distance between photometer and microscope or by changing the lens system of the microscope. A coarse-grained negative required a low magnification,

[1] This number, p. 321.

because otherwise the photometer would be measuring the density of the individual grains.

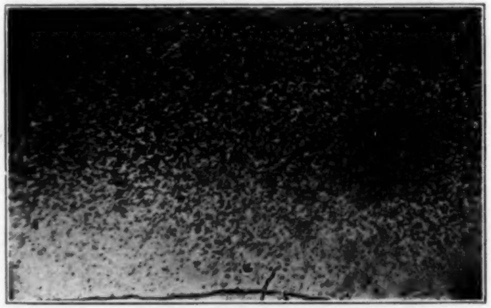
This apparatus avoids the complication arising from the pinhole image found in the Koch instrument. Also, the resolving power of the König-Martens photometer can be adjusted within wide limits, so that the correction for slit-width is practically nothing in all cases. However, there is one difficulty which was also found in the Koch microphotometer. The readings for densities which are above 1.5 are erroneous, in that the instrument gives the same readings for all densities about $F5$. But below this value a calibration showed the instrument to be correct within the limits of observation. The trouble undoubtedly comes from light scattered in the microscope system.

The results of these measurements are shown in Figs. 3, 4, 5, and 6. The maximum density is indicated in Fig. 3. This was obtained by measuring the density on a König-Martens photometer without the microscope attachment and continuing the curve to the proper value. In the other curves this maximum density is not indicated, because the curve as made gives sufficient length to determine the slope. Each pair of curves was made from different exposures and each member of the pair was given a different development.

An explanation of the departure of this result from that expected from theory may be found in the penetration of the developer. The top layer of the emulsion is developed first and as development proceeds the layer of reduced silver becomes thicker. The photomicrographs in Plate VI, *a* and *b*, show the penetration of a metol-hydrochinon developer. These sections were swelled out with water before photographing. The density-gradient, therefore, for long development would extend over a greater distance but would not be steeper than for short development.

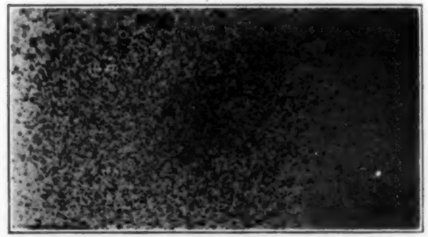
The variation of density-gradient with wave-length of exposing light may be explained by the difference in optical opacity of the emulsion for different wave-lengths. The variation of photographic gradient is not enough and not in the right direction to account for the variation of resolving power with wave-length. In general, the sensitiveness-curve of a plate exposed to green light

PLATE VI

a


b


a and *b*. Photomicrographs showing penetration of a metolhydrochinon developer, five and two minutes respectively.


c


d

c and *d*. Cross-section of emulsion film, showing distribution of the grains at point where the edge of the image occurs.

is steeper than the curve of the same emulsion exposed to violet light. Also, the depth of penetration of green light is greater than that of shorter wave-length. Therefore, if the optical opacity for the long wave is less than for the short waves the light-gradient

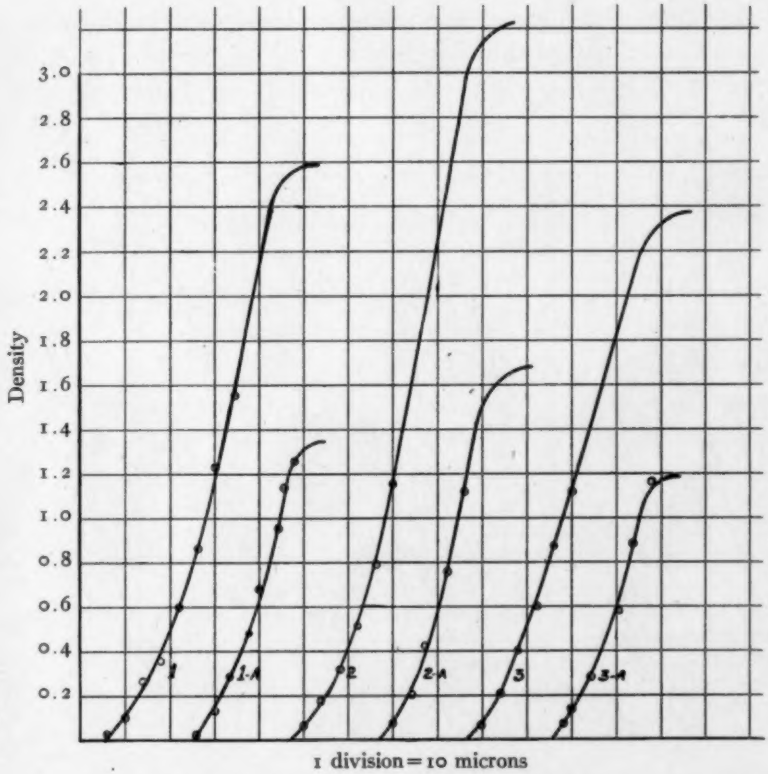


FIG. 3.—Seed "Process" plates exposed to green light. Equal exposure, but varying development, i.e.,

1, developed 2 minutes
1-A, developed 5 minutes

in the emulsion film will be less steep for green light than for violet light, and, consequently, there will be more spreading of the image made by green light. The larger value of the photographic gradient is overbalanced by the lower value of the light-gradient. This explanation assumes that the scattering of the light by the silver

halide grains does not vary appreciably with wave-length. This assumption is justified by the fact that it is the short waves which usually are scattered most by heterogeneous media and on this account the resolving power of a photographic plate should be greater for long waves than for short waves. Further evidence that the opacity of the emulsion is a more important factor in the light-gradient than the diffusion is given in the curves 4, 4 A of Fig. 4. A "Process" plate was immersed in a yellow dye and

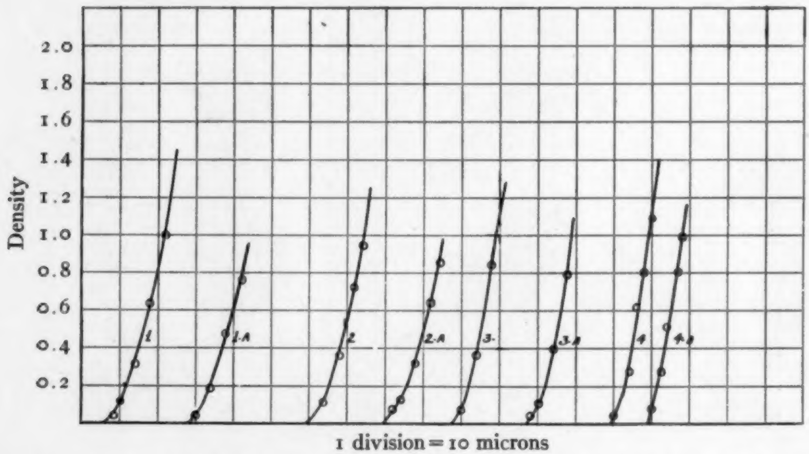


FIG. 4.—Seed "Process" plates exposed to violet light. Equal exposure, but varying development, i.e.,

1, developed 2 minutes
1-A, developed 5 minutes
4 and 4-A, plates bathed in yellow dye previous to exposure

exposed to violet light. In this case the diffusion could not be changed, but the opacity was increased with a corresponding increase of resolving power.

The curves in Figs. 3, 4, and 5 are all from images exposed and developed within the range of ordinary working conditions. A long exposure will show the distribution of the light in the emulsion as explained in the first part of this paper. The curves for long exposures are in Fig. 6. Here there is a decided change in the density-gradient with development. If the exposure could be timed just right, a density-gradient could be obtained showing

the very beginning of the curve to grow steeper with long development. It appears, then, that in ordinary exposure the lateral spread of exposure is not sufficient to permit the density-gradient to become steeper with prolonged development.

A cross-section of the emulsion film (Plate VI, *c* and *d*) at the point where the edge of the image occurs shows the distribution of the

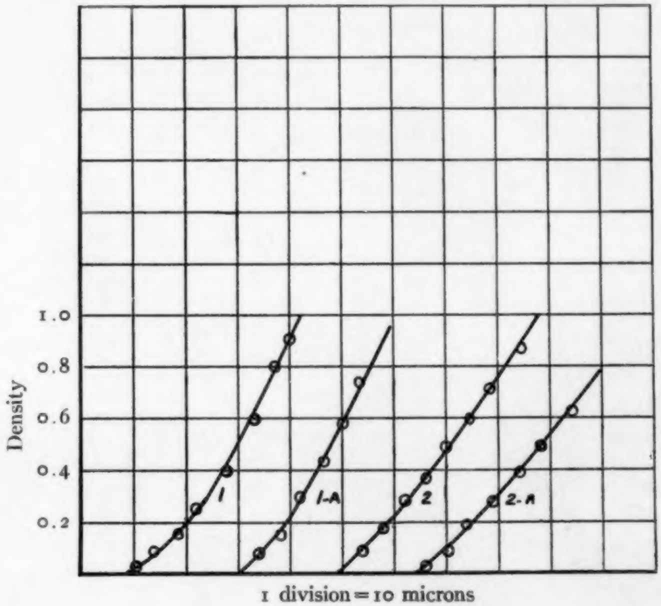


FIG. 5.—Seed "30" plates

1 and 1-A, exposed equally to violet light, but developed 2 and 5 minutes respectively.

2 and 2-A, exposed equally to green light, but developed 2 and 5 minutes respectively.

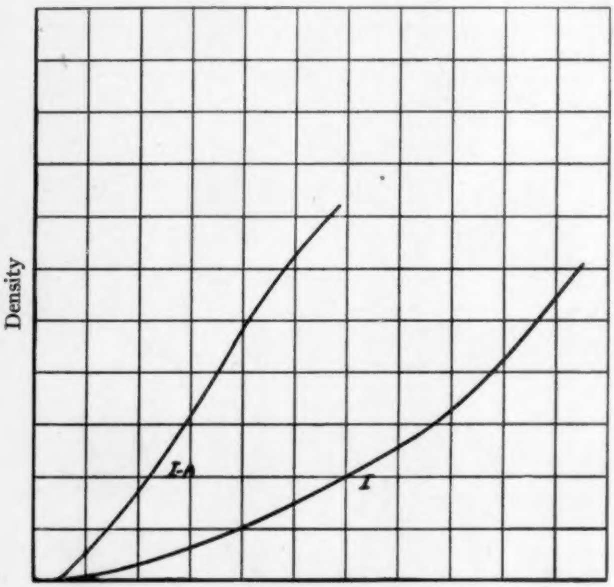
grains at this point. It is seen that the greatest spreading occurs at the top of the film. This distribution suggests that the intensity of the light in the emulsion at any point is given by the equation

$$I = I_0 e^{-k(x+y)}$$

where x is the distance down through the emulsion and y is the distance out from the image and measured from the region of uniform exposure. The validity of this equation is supported by previous

investigations on the absorption of light in heterogeneous media. The logarithmic character of the law of light-absorption in such media was shown theoretically by Nutting[1] and experimentally by the writer.[2]

A study of these overexposures opens a way for the determination of the exposure-gradient. Goldberg's investigation was essen-



1 division = 10 microns

FIG. 6.—Seed "30" plate, over-exposed to violet light
1, developed 2 minutes
1-A, developed 5 minutes

tially a study of overexposures, but his methods failed to reveal the nature of the factor desired. On some points, however, the investigation will be similar to Goldberg's procedure.

It was pointed out above that exposures do not affect this distribution of light in the emulsion and that spreading of the image results from the diffused light having time to expose the adjacent sensitive material. If the exact position of the knife-edge on the emulsion can be located and the density is measured at a given

[1] *Phil. Mag.* (6), **26**, 423, 1913. [2] Tugman, *Photographic Journal*, June 1914.

distance from that edge for various exposures and developments, the true value of the exposure-gradient can be found by referring these densities to a sensitiveness-curve of the emulsion being investigated. Two parallel knife-edges placed at a known distance apart on a photographic plate would permit an exposure over a rectangular area. The density-curve taken across such an exposed area would show the falling off of density on both sides and the position of the knife-edges with respect to the exposed area. This is a subject for further experimental work.

The writer is indebted to Dr. C. E. K. Mees and Dr. P. G. Nutting for their interest and suggestions in this investigation.

ROCHESTER, N.Y.
July 22, 1915

THE VARIATION WITH TEMPERATURE OF THE ELECTRIC FURNACE SPECTRA OF COBALT AND NICKEL[1]

By ARTHUR S. KING

The treatment in this paper of the electric furnace spectra of cobalt and nickel follows the method previously used for the spectra of iron,[2] titanium,[3] vanadium and chromium,[4] the lines being classified according to the temperature at which they first appear and their rate of increase in intensity as the temperature rises. The range of wave-length covered extends from below λ 3000 to about λ 7100.

APPARATUS AND METHODS

The operation of the tube resistance furnace *in vacuo* has been described in former papers. The spectrum was photographed with a 15-ft. concave grating in the vertical spectrograph.[5] The second order (scale 1 mm = 1.85 A) was used as far as λ 5200, and the first order from this point to λ 6700, a few lines at the red end being recorded on films taken with a 1-meter concave grating.

The three temperatures on which the classification of spectrum lines is based were given by a Wanner pyrometer as 2000–2100° C. for the low-, about 2300° C. for the medium-, and 2500–2600° C. for the high-temperature plates. A meager spectrum, consisting of the stronger low-temperature lines of both elements, mainly in the blue region, was obtained as low as 1850° C.

The metallic cobalt and nickel used in the furnace were highly purified preparations by Kahlbaum, each of them showing but a trace, spectroscopically, of the other element. As the furnace tubes were of regraphitized Acheson graphite, there was little disturbance

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 108.

[2] *Mt. Wilson Contr.*, No. 66; *Astrophysical Journal*, **37**, 239, 1913.

[3] *Mt. Wilson Contr.*, No. 76; *Astrophysical Journal*, **39**, 139, 1914.

[4] *Mt. Wilson Contr.*, No. 94; *Astrophysical Journal*, **41**, 86, 1915.

[5] *Mt. Wilson Contr.*, No. 84; *Astrophysical Journal*, **40**, 205, 1914.

from impurity lines, the main trouble from this source being the strong carbon bands given at the higher temperatures.

EXPLANATION OF THE TABLES

Wave-lengths.—The wave-lengths in Tables I and II are those given by Exner and Haschek[1] for the arc spectrum, supplemented occasionally by those of Hasselberg,[2] designated by "H" usually in cases where close doublets were not resolved by Exner and Haschek.

An asterisk after the wave-length denotes that an explanatory remark for the given line is to be found at the end of the table.

The sign † indicates that the estimates of intensity for the line in the furnace spectrum are disturbed by the presence of a band spectrum, this being usually one of the heads of the "Swan spectrum" of carbon, though a banded structure farther in the red, whose origin has not been definitely fixed, interfered with a few lines.

Arc intensities.—These were estimated by the writer from spectra given by the purified cobalt or nickel in the carbon arc, the exposure being timed to produce as distinct intensity contrasts as possible. Nebulous lines, occurring for the most part in the nickel spectrum, are indicated by "n" after the intensity value. The letters "R" and "r," both for arc and for furnace lines, indicate complete and partial self-reversal, respectively.

Furnace intensities.—The columns devoted to the intensities of furnace lines give the relative strength as estimated for each temperature, a line distinctly outlined on the plate being given the intensity "1," a fainter appearance being indicated as a trace, "tr". There is usually a decided difference in appearance between lines in the furnace at different temperatures, and also between furnace lines and those of the arc, but the relative change of different lines with increase of temperature is shown in the tables.

Classification.—The method of assigning lines to the classes given in the last column of Tables I and II is the same as for the spectra previously treated. Class I lines are relatively strong at

[1] *Spektren der Elemente bei normalem Druck*, Leipzig, 1911.

[2] *Kgl. svenska vet. akad. handl.*, **28**, 1896; see also Kayser, *Handbuch der Spectroscopie*, **5**, 310; **6**, 172.

low temperature and strengthen slowly at higher temperatures. Class II lines appear at low temperature, but strengthen more rapidly than those of Class I as the tube becomes hotter. The lines of Class III are absent or faint at low temperature, appear at medium temperature, and are usually considerably stronger at high temperature. Class IV lines appear at the highest furnace temperature, sometimes faintly at medium temperature; while those of Class V are usually absent in the furnace, or if present are faint compared with the arc intensity. Arc lines below a certain minimum intensity are not entered in the tables unless they appear also in the furnace.

The use of "A" after the class number indicates that the line in question is relatively weak in the arc, being usually not more than half as strong as in the high-temperature furnace.

LEADING CHARACTERISTICS OF THE FURNACE CLASSES

Class I.—The lines of this class are of a well-defined and fairly uniform type. With few exceptions, the scale adopted gives them nearly the same intensity at the three furnace temperatures and in the arc, while the lines of other classes decrease with varying degrees of rapidity from high to low temperature. A large proportion of the Class I lines are of moderate strength and unreversed. These are very similar in appearance at all furnace temperatures. A considerable number, however, reverse at high and sometimes at medium temperature, while at low temperature the lines are sharp but still strong. A few lines of this class maintain their strength at low temperature to an unusual degree, these coming out strongly at the lowest temperature at which the vapor radiates. In general, however, the higher temperatures do not seem to be at a disadvantage in producing the low-temperature lines, the rule prevailing that a line strong at low temperature is strong at all temperatures; though in the case of Class I A lines it may be weak in the arc. The question arises whether, when the furnace is operated at high temperature, the Class I lines may be radiated chiefly by the cooler vapor which is doubtless present near the ends of the tube. This seems improbable since the ratio of exposure times for high and low temperature is of the order of 1:50, so that

TABLE I

Temperature Classification of Cobalt Lines

λ (Exner and Haschek)	Arc	Furnace			Class	λ (Exner and Haschek)	Arc	Furnace			Class
		High Temp.	Medium Temp.	Low Temp.				High Temp.	Medium Temp.	Low Temp.	
2982.37....	1	1	1	.....	III	3104.12*...	5	5	4	tr	III
2987.28....	15r	15R	10r	5	II	3106.03....	3	3	3	1	II
2989.70....	15r	15R	10r	5	II	3106.22....	1	3	2	tr	III A
2996.67....	1	tr	.....	.....	IV	3107.15....	3	3	1	.....	III
2999.84....	1	tr	.....	.....	IV	3107.65....	1	1	.....	.....	IV
3000.66....	7	5r	3	2	II	3109.60....	4	3	2	.....	III
3005.86....	3	2	1	.....	III	3110.12....	5	3	2	.....	III
3013.70....	8	10r	6r	2	II	3110.94....	5	4	4	3	I
3015.77....	3	3	2	.....	III	3111.45....	2	1	tr	.....	III
3017.33....	3	1	1	.....	III	3113.58....	6	6	4	1	III
3017.66....	15r	15R	10r	3	II	3118.35....	5	8r	5	3	II
3022.47....	3	2	1	.....	III	3118.76....	1	4	3	1	II A
3026.49....	6	3	2	tr	III	3121.54....	10	12R	10r	5	II
3031.43....	2	1	tr	.....	III	3121.69....	10	12R	10r	5	II
3034.55....	6	6r	4	2	II	3126.60....	1	1	.....	.....	IV
3038.42....	2	2	2	.....	III	3126.85....	4	3	1	.....	III
3039.66....	3	2	1	.....	III	3127.35....	7	8r	6	5	I
3040.93....	1	1	.....	.....	IV	3129.10....	3	5	5	2	II
3042.60....	8	10r	5r	2	II	3129.57....	3	3	1	.....	III
3044.11....	30R	30R	20R	10r	II	3131.96....	1	1	.....	.....	IV
3048.21....	2	1	.....	.....	IV	3132.33....	4	6r	6	3	II
3049.00....	12r	12R	8r	3	II	3136.81....	5	6r	3	2	II
3050.64....	3	2	1	.....	III	3137.10....	1	1	tr	.....	III
3054.84....	4	5	3	2	II	3137.47*...	{10	10R	8r	5	II
3060.17....	5	5	3	tr	III		3	3	1	.....	III
3061.15....	1	1	tr	.....	III	3137.75....	4	4	2	.....	III
3061.94....	20r	20R	15R	8r	II	3140.08*...	12	12R	10r	5	II
3062.33*...	5	?	3	2	II	3140.83....	2	2	tr	.....	IV
3064.49....	5	5r	4	2	II	3145.16....	3	3	1	.....	III
3070.94....	1	tr	.....	.....	IV	3147.19....	15r	15R	12r	5	II
3072.06....	6	5r	4	3	I	3149.43....	10	8R	6r	4	II
3072.45....	15r	15R	12r	6r	II	3150.82....	2	.....	.....	.....	V
3073.64....	3	3	2	.....	III	3150.93....	2	.....	.....	.....	V
3079.49....	5	5	4	2	II	3152.84....	6	5	4	tr	III
3082.73....	12r	12R	10R	5r	II	3154.78....	5	3	1	.....	III
3082.96....	2	2	1	.....	III	3154.91....	10	5	5	3	II
3086.46....	4	3	2	tr	III	3157.23....	1	1	tr	.....	III
3086.89....	15r	15R	12R	6r	II	3158.92....	12	12R	12r	6	II
3087.86....	3	3	1	.....	III	3159.80....	10	8R	6	5	II
3088.76....	1	3	1	.....	III A	3161.78....	5	4	3	tr	III
3089.68....	10	10R	8r	4	II	3168.19*...	6	8	4	tr	III
3090.36....	4	4	2	.....	III	3169.90....	9	5	4	tr	III
3095.81....	3	4	2	.....	III	3173.30....	1	1	tr	.....	III
3096.50....	3	3	2	.....	III	3174.29....	2	1	tr	.....	III
3096.80....	2	2	1	.....	III	3175.06....	4	6	3	.....	III
3098.30....	10	10R	8r	4	II	3177.40....	8	4	2	.....	III
3099.76....	2	2	1	.....	III	3179.98....	1	tr	.....	.....	IV
3102.49....	4	3	2	tr	III	3180.42....	2	1	1	.....	III
3103.82....	5	5	3	tr	III	3182.25....	7	5	4	tr	III

TABLE I—*Continued*

λ (Exner and Haschek)	Arc	Furnace			Class	λ (Exner and Haschek)	Arc	Furnace			Class
		High Temp.	Medium Temp.	Low Temp.				High Temp.	Medium Temp.	Low Temp.	
3186.05....	2	3	1	.....	III	3283.60....	9	7	7	5	I
3186.46....	5	5	5	4	I	3283.95....	3	5	2	1	II
3188.50....	7	6	4	1	III	3286.66....	1	1	tr	.....	III
3189.87....	5	5	5	4	I	3287.34....	7	4	5	2	II
3191.44....	4	6	5	3	II	3287.69....	2	1	tr	.....	III
3192.35....	3	2	1	.....	III	3292.24....	3	4	2	.....	III
3193.30....	5	6	5	3	II	3293.37....	3	1	tr	.....	III
3198.79....	5	5	5	3	II	3294.04....	2	2	1	.....	III
3199.44....	4	3	3	3	I	3294.69....	2	tr	.....	.....	IV
3203.15....	4	3	3	3	I	3298.83....	6	5	4	1	III
3206.00....	1	1	.....	.....	IV	3304.03....	4	4	3	1	II
3210.35....	5	4	2	.....	III	3304.29....	3	tr	.....	.....	IV
3210.96....	3n	1	.....	.....	IV	3304.95....	1	tr	.....	.....	IV
3215.46....	1	tr	.....	.....	IV	3305.27....	2	tr	.....	.....	IV
3217.15....	1	1	tr	.....	III	3305.87....	2	1	tr	.....	III
3219.31....	5	8R	5	4	II	3306.54....	1	tr	.....	.....	IV
3223.30....	1	3	3	tr	III A	3307.31....	7	6	5	2	II
3224.80....	4	4	2	.....	III	3308.65....	4	2	1	.....	III
3227.15....	4	2	1	.....	III	3308.96....	4	2	1	.....	III
3227.93....	2	4	4	2	II A	3312.33....	7	5	5	2	II
3234.30....	1	1	.....	.....	IV	3312.99....	3	1	tr	.....	III
3235.69....	6	4	3	1	II	3313.27....	2	tr	.....	.....	IV
3237.18....	8	10R	8r	4	II	3314.21....	8	5	3	.....	III
3243.70....	2	2	1	.....	III	3314.46....	2	.....	.....	.....	V
3243.99....	8	7	6	3	II	3315.20....	3	1	tr	.....	III
3247.13....	4	3	2	.....	III	3318.55....	4	5	3	1	II
3247.32....	8	6	6	3	II	3319.31....	4	2	1	.....	III
3250.17....	6	8r	5	4	II	3319.66....	8	4	3	1	II
3253.60....	1	tr	.....	.....	IV	3320.00....	4	2	1	.....	III
3254.37....	12	10	9	6	II	3322.06....	2	1	1	.....	III
3258.16....	4	5	3	tr	III	3322.41....	8	8	5	1	III
3258.58....	1	1	tr	.....	III	3325.44....	10	6	6	3	II
3260.99....	9	6	5	2	II	3326.72....	2	4	2	.....	III A
3263.35....	4	4	2	.....	II	3327.14....	8	5	3	tr	III
3264.96....	5	5	5	4	I	3328.34....	3	1	tr	.....	III
3265.49....	3	4	2	.....	III	3329.16....	2	1	tr	.....	III
3268.15....	1	tr	.....	.....	IV	3329.63....	5	3	1	.....	III
3269.04....	1	1	tr	.....	III	3333.55....	10	8r	8	8	I
3270.35....	2	tr	.....	.....	IV	3334.31....	30r	30R	20R	15	II
3271.92....	8	5	5	2	II	3337.34....	8	8r	8	10	I
3276.60....	4	2	1	.....	III	3338.68....	1	1	tr	.....	III
3277.44....	4	5	3	tr	III	3339.97....	8	5	3	tr	III
3277.80....	3	1	tr	.....	III	3341.52....	5	4	2	.....	III
3278.23....	2	tr	.....	.....	IV	3342.10....	5	4	2	.....	III
3278.96....	6	5	4	1	III	3342.88....	8	10r	6	1	III
3279.39....	5	4	3	1	II	3344.36*...	2	2	1	.....	III
3281.75....	2	4	5	3	I A	3346.45....	1	2	1	.....	III A
3282.23....	1	tr	.....	.....	IV	3347.10....	8	5	2	.....	III
3282.37....	1	1	tr	.....	III	3348.28....	8	7	5	2	II
3283.49....	4	4	1	.....	III	3351.29....	1	tr	.....	.....	IV

TABLE I—*Continued*

λ (Exner and Haschek)	Arc	Furnace			Class	λ (Exner and Haschek)	Arc	Furnace			Class
		High Temp.	Medium Temp.	Low Temp.				High Temp.	Medium Temp.	Low Temp.	
3351.70....	3	1	tr	.....	III	3417.84....	5	4	1	.....	III
3354.34*...	4	?	?	.....	III?	3417.93....	6	6	6	6	I
3354.51....	20	20R	15R	10	II	3420.64....	5	5	3	1	II
3355.27....	3	2	1	.....	III	3420.95....	7	7	5	1	III
3356.06....	2	2	1	.....	III	3421.77....	3	3	2	.....	III
3356.59....	6	8	5	tr	III	3422.63....	1	tr	.....	.....	IV
3356.97....	3	1	tr	.....	III	3423.03....	4	5	4	1	III
3358.13....	3	2	1	.....	III	3424.67....	10	8	7	3	II
3359.20....	3	3	1	.....	III	3426.60....	3	1	tr	.....	III
3359.42....	6	6	5	1	III	3427.90....	2	1	.....	.....	IV
3361.72*...	5?	3?	2	.....	III	3428.34....	6	3	1	.....	III
3362.93....	6	4	2	.....	III	3428.89....	3	1	tr	.....	III
3363.41....	4	2	1	.....	III	3429.82....	1	tr	.....	.....	IV
3363.89....	3	1	.....	.....	IV	3431.76....	50r	50R	35R	20r	II
3364.38....	4	5	3	.....	III	3432.46*...	3	3	2	.....	III
3365.13....	2	2	1	.....	III	3433.18....	60R	60R	40R	25	II
3367.25....	30r	30R	20R	15	II	3437.10....	3	1	tr	.....	III
3370.48....	10	10r	10	10	I	3437.83....	6n	3	1	.....	III
3373.40....	7	6	4	1	III	3438.83....	4	5	3	tr	III
3374.13....	4	5	4	1	III	3439.05....	5	2	tr	.....	IV
3374.42....	5	1	1	.....	III	3441.28....	2	tr	.....	.....	IV
3376.34....	2	1	tr	.....	III	3443.06....	40r	40R	30R	20	II
3377.20....	5	6	6	2	II	3443.31*...	5	?	?	.....	III?
3378.50....	3	1	tr	.....	III	3443.79....	80R	80R	60R	30r	II
3378.86....	5	3	1	.....	III	3445.29....	1	1	1	.....	III
3381.65....	4	5	4	tr	III	3446.21....	12	4	2	.....	III
3382.20....	2	2	1	.....	III	3447.43....	3	tr	.....	.....	IV
3384.09....	4	2	1	.....	III	3448.49....	4	1	tr	.....	III
3385.38....	25r	25R	20R	15	II	3449.26....	60R	50R	40R	30r	II
3387.19....	1	tr	.....	.....	IV	3449.54....	60R	60R	50R	30r	II
3387.56....	1	tr	.....	.....	IV	3452.44....	3	1	1	.....	III
3388.29....	30r	30R	20R	15	II	3453.66....	200R	200R	125R	80R	II
3388.80....	1	1	tr	.....	III	3455.33....	25r	25R	20R	20	I
3390.54....	5	5	4	1	III	3456.58*...	{ 1	tr	.....	.....	IV
3390.92....	3	1	tr	.....	III		1	tr	.....	.....	IV
3395.07....	2	2	1	.....	III	3457.05....	9	8r	8	8	I
3395.55....	40r	40R	30R	20	II	3458.16....	3	4	2	.....	III
3396.61....	1	1	tr	.....	III	3460.86....	4	5	6	4	I
3398.96....	3	1	tr	.....	III	3461.33....	15	4	3	tr	III
3399.54....	1	tr	.....	.....	IV	3462.94....	60r	60R	40R	30r	II
3400.63....	1	1	tr	.....	III	3463.62....	3	3	2	.....	III
3401.74....	2	3	2	.....	III	3465.96....	100R	100R	80R	60R	II
3402.14....	4	1	tr	.....	III	3467.37....	1	1	.....	.....	IV
3405.27....	150R	150R	100R	60R	II	3468.74....	1	tr	.....	.....	IV
3409.05*...	2	?	.....	.....	IV?	3469.11....	3	1	tr	.....	III
3409.29....	60r	60R	40R	20r	II	3471.53....	7	4	2	.....	III
3412.50....	80R	80R	50R	30r	II	3472.34....	1	tr	.....	.....	IV
3412.79....	80R	80R	50R	40R	II	3473.60....	1	1	1	.....	III
3415.66....	5	6	6	6	I	3474.17....	100R	100R	60R	40r	II
3417.32....	50r	50R	35R	20	II	3474.40*...	6	?	?	?	?

TABLE I—*Continued*

λ (Exner and Haschek)	Arc	Furnace			Class	λ (Exner and Haschek)	Arc	Furnace			Class
		High Temp.	Medium Temp.	Low Temp.				High Temp.	Medium Temp.	Low Temp.	
3474.68....	6	6	6	6	I	3548.60....	7	7	6	2	II
3476.50....	5n	1	.....	.....	IV	3550.78....	20r	20R	20R	15	I
3478.00....	4	1	tr	.....	III	3551.84....	2	1	1	.....	III
3478.60....	8	6	4	1	III	3552.90....	8	10r	10	10	I
3478.90....	7	7	5	2	II	3553.16....	8	6	6	2	II
3479.74....	1	1	1	.....	III	3553.31....	2	1	tr	.....	III
3480.17....	6	6	4	2	II	3558.93....	12	12r	12	10	I
3483.29....	2	2	1	.....	III	3559.75....	1	tr	.....	.....	IV
3483.58....	20r	20R	20R	15	I	3560.47....	5	6	3	.....	III
3485.51....	15	6	4	1	III	3561.03....	20r	20R	20R	15	I
3485.85....	4	4	3	1	II	3562.25....	6	6	3	.....	III
3487.84....	8	6	5	2	II	3563.09....	7	9	6	2	II
3489.57....	60r	40R	30R	20	II	3564.31....	4	2	1	.....	III
3490.89....	10	8r	8	8	I	3565.09....	25r	25R	25R	20	I
3491.49....	15	20R	20R	15	I	3568.56....	2	2	1	.....	III
3492.12....	3	1	tr	.....	III	3569.59....	80R	70R	50R	25	II
3495.83....	50r	50R	40R	25	II	3570.57....	4n	3	2	1	II
3496.20....	3	1	tr	.....	III	3575.13....	25r	25R	20R	15	I
3496.80....	15	15R	12r	12	I	3575.53....	60r	60R	50R	30R	II
3496.90....	6	6	3	.....	III	3577.39....	3	4	3	1	II
3502.45....	100R	100R	60R	40R	II	3577.82....	2	.....	.....	.....	V
3502.80....	20r	20R	20R	20	I	3578.21....	6	6	3	1	II
3503.85....	3	3	1	.....	III	3579.04....	6	5	4	2	II
3504.89....	5	4	2	.....	III	3579.15....	6	6	5	2	II
3505.29....	3	2	1	.....	III	3582.02....	4	4	2	1	II
3506.47....	80R	80R	50R	30r	II	3584.94....	15	15R	12r	10	I
3510.00....	50r	40R	30R	25	II	3585.33....	25R	25R	20R	15	I
3510.59....	30r	30R	30R	25	I	3585.94....	4	4	3	1	II
3512.80....	60R	50R	40R	25	II	3586.20....	3	2	1	.....	III
3513.61....	50R	50R	40R	30r	II	3587.30....	70R	60R	40R	25	II
3516.78....	1	1	1	.....	III	3591.91....	4	3	2	.....	III
3518.50....	50R	40R	20R	15	II	3595.03....	50R	50R	40R	20	II
3520.23....	15	20R	20R	10	II	3596.67....	5	5	3	.....	III
3521.73....	30r	30R	30R	20	I	3600.97....	3	4	3	tr	III
3521.85....	5	5	5	5	I	3602.22....	40R	40R	30R	20	II
3523.00....	4	1	tr	.....	III	3604.62....	4	1	1	tr	II
3523.55....	25r	20R	20R	20	I	3605.17....	5	6	5	1	III
3523.83....	7	5	5	2	II	3605.52....	20r	20R	15r	15	I
3526.00....	3	4	2	.....	III	3608.45....	3	10	8	3	II A
3526.97....	100R	100R	80R	50R	II	3609.94....	4	1	1	.....	III
3528.09....	5	2	1	.....	III	3611.89....	10	8	6	3	II
3529.19....	30r	30R	25R	20	I	3615.54....	6	7	5	2	II
3529.96....	80R	80R	50R	30r	II	3618.15....	4	9	7	3	II A
3530.70....	1	1	tr	.....	III	3620.56....	5	5	3	tr	III
3533.51....	25r	25R	25R	20	I	3624.54....	5	7	4	1	III
3534.91....	4	4	2	.....	III	3625.18....	8	12r	9	8	I
3537.85....	1	1	tr	.....	III	3626.20....	2	4	2	.....	III A
3543.15....	2	5	5	2	II A	3627.98....	25r	25R	20R	15	I
3543.43....	15	8	8	5	II	3631.59....	20r	25R	25R	18	I
3546.85....	6	5	4	1	III	3632.12....	2	1	1	.....	III

TABLE I—*Continued*

λ (Exner and Haschek)	Arc	Furnace			Class	λ (Exner and Haschek)	Arc	Furnace			Class
		High Temp.	Medium Temp.	Low Temp.				High Temp.	Medium Temp.	Low Temp.	
3633.01....	7	5	3	tr	III	3750.07....	9	6	6	3	II
3633.49....	2	1	1	.....	III	3751.75....	5	8	4	1	III
3634.86....	7	5	3	tr	III	3754.47....	4	2	1	.....	III
3636.84....	6	6	5	2	II	3755.60....	10	10	7	3	II
3637.44....	4	3	2	.....	III	3759.83....	3	2	1	.....	III
3638.50....	1	1	tr	.....	III	3760.55....	4	5	4	2	II
3639.60....	10	10	8	5	II	3774.75....	8	10	6	2	II
3641.94....	6	7	4	3	II	3777.25....	1	1	tr	.....	III
3643.35....	9	8	6	4	II	3777.68....	6	8	5	1	III
3645.34....	5	6	4	1	III	3805.94....	2	2	1	.....	III
3645.60....	3	3	2	tr	III	3808.25....	10	10R	10r	12	I
3647.23....	5	5	3	tr	III	3811.23....	5	7	6	5	I
3647.56....	1	1	tr	.....	III	3812.62....	4	4	3	tr	III
3647.85....	12	15R	15r	15	I	3814.62....	5	5	4	1	III
3648.26....	3	2	1	.....	III	3816.48....	15	6	5	4	I
3649.49....	8	8	4	tr	III	3816.61....	15	6	5	4	I
3651.41....	4	5	4	1	III	3817.01....	5	5	3	1	II
3652.70....	15	20R	20R	20	I	3820.08....	4	5	3	1	II
3654.59....	5	6	5	2	II	3823.66....	1	tr	.....	.....	IV
3657.10....	7	8	8	10	I	3841.60....	5	4	4	4	I
3658.06....	2	1	1	.....	III	3842.21....	30	20R	15r	10	II
3662.32....	12	8	7	4	II	3843.85....	4	4	3	tr	III
3668.80....	1	1	tr	.....	III	3845.60....	60	60R	40R	30R	II
3670.20....	3	3	2	tr	III	3850.27....	5	4	3	.....	III
3676.72....	12	10	5	1	III	3851.09....	4	10r	8	8	I A
3683.22....	20	20	15	10	II	3852.00....	2	2	1	.....	III
3684.63....	10	12	6	1	III	3856.94....	4	2	2	.....	III
3685.11....	2	2	1	.....	III	3861.31....	20	20R	15r	15	I
3686.62....	2	1	tr	.....	III	3863.75....	2	1	tr	.....	III
3690.91....	7	6	4	2	II	3870.66....	4	3	1	.....	III
3693.29....	8	8	8	5	I	3873.23....	60	60R	40R	30R	II
3693.53 H..	2	2	1	.....	III	3874.09....	40	40R	30R	20R	II
3693.63....	8	6	7	5	I	3877.01....	20	20R	15r	15	I
3699.15....	2n	1	.....	.....	IV	3882.06....	25	20R	18R	15r	I
3702.39....	12	8	5	1	III	3884.79....	10	8r	8	6	I
3704.22....	25	30R	20	20	I	3885.45....	6	6	6	4	I
3707.62....	6	5	4	2	II	3890.18....	2	2	1	.....	III
3709.00....	12	9	8	5	II	3891.85....	2	.....	.....	.....	V
3711.83....	3	2	2	tr	III	3892.30....	3	2	1	.....	III
3712.35....	6	5	4	1	III	3893.20....	2	1	1	.....	III
3726.79....	5	6	4	1	III	3893.45....	2	.....	.....	.....	V
3728.96....	3	2	1	.....	III	3894.25....	60	50R	30R	20R	II
3730.63....	20	15	12	8	II	3895.15....	20	20R	15R	8	II
3731.42....	2	2	2	tr	III	3898.54....	4	5	5	1	III
3732.59....	20	15	12	12	I	3904.23....	2	.....	.....	.....	V
3733.65....	12	10	8	5	II	3904.94....	3	.....	.....	.....	V
3734.30....	7	7	5	2	II	3905.70....	2	.....	.....	.....	V
3736.08....	12	12	9	4	II	3906.46....	10	12r	12r	10	I
3740.34....	5	4	3	1	II	3910.13....	15	20R	20R	15r	I
3745.65....	25	30R	20r	20	I	3917.80....	8	6	5	2	II

TABLE I—*Continued*

λ (Exner and Haschek)	Arc	Furnace			Class	λ (Exner and Haschek)	Arc	Furnace			Class
		High Temp.	Medium Temp.	Low Temp.				High Temp.	Medium Temp.	Low Temp.	
3920.32....	2	1	1	.....	III	4023.55....	4	4	4	1	III
3920.75....	2	1	1	.....	III	4027.18....	10	10r	10r	10	I
3920.90....	4	3	3	1	II	4035.74....	8	3	1	.....	III
3921.27....	1	tr	.....	.....	IV	4040.95....	2	2	2	tr	III
3922.90....	7	8	8	7	I	4045.56....	20	20R	15r	15	I
3925.33....	3	1	tr	.....	III	4053.10....	3	1	1	.....	III
3929.43....	3	1	tr	.....	III	4054.08....	1	1	.....	.....	IV
3934.07....	6	8	6	6	I	4057.10....	2	.....	.....	.....	V
3934.85....	1	1	tr	.....	III	4057.36....	5	8r	8	8	I
3935.44....	1	1	1	.....	III	4058.36....	8	10r	10	10	I
3936.13....	30	30R	15R	10	II	4058.76....	6	6	6	2	II
3939.00....	3	.....	.....	.....	V	4066.56....	15	12r	10	10	I
3939.21....	2	.....	.....	.....	V	4068.72....	8	7	6	3	II
3941.06....	12	12r	10r	8	I	4069.71....	1	tr	.....	.....	IV
3941.91....	20	20R	15r	10	II	4076.30....	3	8	8	7	I A
3942.84....	2	tr	.....	.....	IV	4077.56*...	2	2	1	.....	III
3945.07....	1	tr	.....	.....	IV		2	.....	.....	.....	V
3945.51....	15	15r	12r	12	I	4081.64....	2	.....	.....	.....	V
3946.75....	2	2	2	1	II	4082.75....	2	5	5	4	I A
3947.26....	3	3	3	1	II	4083.78....	1	1	.....	.....	IV
3952.46....	8	8r	8	7	I	4086.49....	15	15	12	6	II
3953.10....	25	25R	15r	12	II	4088.45....	1	8	8	6	I A
3958.10....	15	15R	12r	8	II	4092.56....	25	20R	15r	15	I
3961.15....	6	4	2	1	II	4093.03....	3	2	1	.....	III
3965.15....	1	2	2	1	II A	4093.22....	2	.....	.....	.....	V
3965.37....	2	4	4	2	II A	4096.11....	2	.....	.....	.....	V
3968.75....	1	2	2	1	II A	4104.57....	2	2	2	tr	III
3969.28....	8	5	4	1	III	4104.91....	4	3	2	tr	III
3972.69....	6	1	tr	.....	III	4110.70....	25	20R	15r	15	I
3973.31....	10	10	10	3	II	4118.96....	50	50R	30R	15r	II
3974.90....	10	15R	12r	12	I	4121.52....	60	60R	40R	20r	II
3975.45....	3	2	2	tr	III	4122.43....	2	1	tr	.....	III
3977.34....	3	3	2	tr	III	4132.00....	3	.....	.....	.....	V
3978.78....	10	10r	10	9	I	4132.30....	4	6	6	4	I
3978.99....	4	.....	.....	.....	V	4139.60....	3	3	2	tr	III
3979.67....	10	15R	15R	12	I	4150.62....	2	4	4	2	II A
3987.25....	6	8	8	8	I	4158.59....	4	1	1	.....	III
3990.45....	6	5	4	2	II	4162.32....	2	1	.....	.....	IV
3991.68*...	4	2?	tr	.....	IV	4179.34....	2	1	tr	.....	III
3991.83*...	6	8?	6	6	I	4187.46....	4	4	4	2	II
3994.70....	6	6	5	5	I	4190.88....	20	20R	20r	25	I
3995.45....	60	60R	40R	20R	II	4195.03....	1	1	tr	.....	III
3998.09....	40	40R	20R	15	II	4225.28....	2	2	2	tr	III
4003.85....	2	1	1	.....	III	4234.15*...	2	4	4	6	I A
4008.07....	1	1	tr	.....	III		2	4	4	6	I A
4011.25....	2	4	4	4	I A	4237.50....	1	1	1	.....	III
4014.09....	7	6	5	2	II	4241.69....	2	.....	.....	.....	V
4016.95....	2	.....	.....	.....	V	4242.03....	2	2	1	.....	III
4019.45....	5	8	8	6	I	4245.70....	2	.....	.....	.....	V
4021.07....	20	20R	15R	15	I	4248.30....	2	.....	.....	.....	V

TABLE I—*Continued*

λ (Exner and Haschek)	Arc	Furnace			Class	λ (Exner and Haschek)	Arc	Furnace			Class
		High Temp.	Medium Temp.	Low Temp.				High Temp.	Medium Temp.	Low Temp.	
4252.48	12	12r	12r	15	I	4728.61	3	8	8	12	I A
4268.61	2	1	1	.....	III	4735.01†	2	?	?	.....	III ?
4285.92	6	8	8	10	I	4737.92	2	5	3	1	II A
4303.41	3	10	9	8	I A	4749.89	10	8	4	1	III
4307.58	2	.....	.....	.....	V	4754.60	3	2	1	.....	III
4331.43	3	tr	.....	.....	IV	4768.26	5	3	1	.....	III
4339.80	5	4	2	tr	III	4771.30	6	5	2	.....	III
4371.31†	5	6?	3?	tr	III	4776.51	6	4	2	.....	III
4373.81	6	1	.....	.....	IV	4778.42	2	tr	.....	.....	IV
4375.11	3	2	1	.....	III	4780.20	10	6	3	tr	III
4375.70	2	2	1	.....	III	4781.64	3	10	6	2	II A
4380.29†	5	1?	1?	.....	III ?	4793.10	15	8	4	1	III
4391.78	4	2	1	.....	III	4796.06	2	.....	.....	.....	V
4392.11	3	3	2	.....	III	4796.60	1	15	10	6	II A
4396.09	1	2	1	.....	III A	4813.70	20	10	5	1	III
4402.86	3	1	tr	.....	III	4814.22	2	1	tr	.....	III
4405.08	3	1	1	.....	III	4816.09	1	1	tr	.....	III
4417.55	5	2	1	.....	III	4840.50	25	12	5	1	III
4421.51	4	2	1	.....	III	4843.68	3	1	tr	.....	III
4431.79	3	1	1	.....	III	4868.08	25	12	8	3	II
4445.22	2	1	.....	.....	IV	4882.89	2	1	tr	.....	III
4445.90	4	2	1	.....	III	4899.70	2	8	5	1	III A
4467.09	10	6	3	tr	III	4904.38	1	1	tr	.....	III
4469.75	15	12	5	1	III	4912.58	1	5	4	4	I A
4471.76	5	3	2	.....	III	4920.40	1	3	2	.....	III A
4472.00	1	1	1	.....	III	4928.47	2	3	2	.....	III
4478.50	4	2	1	.....	III	4953.32*	2	10?	10?	10	I A
4484.11	3	2	1	.....	III	4966.72	2	8	8	7	I A
4494.94	2	tr	.....	.....	IV	4972.09	2	1	.....	.....	IV
4514.35	1	1	.....	.....	IV	4988.10	2	6	6	6	I A
4517.26	4	3	1	.....	III	5067.73†	2	?	?	.....	IV ?
4526.95	2	1	tr	.....	III	5077.57†	3	4?	2?	.....	III ?
4528.08	2	1	1	.....	III	5087.97	3	.....	.....	.....	V
4531.12	30	20	10	3	II	5095.13†	8	3?	1	.....	III
4534.18	7	5	2	tr	III	5109.02†	10	1?	.....	.....	V
4543.99	6	6	4	1	III	5113.39†	6	?	?	.....	IV ?
4546.15	1	1	tr	.....	III	5122.93†	8	?	.....	.....	IV ?
4549.89	10	8	4	1	III	5124.89†	2	?	?	.....	IV ?
4565.79	15	12	5	1	III	5125.84†	7	?	.....	.....	IV ?
4570.20	2	tr	.....	.....	IV	5126.36†	10	?	?	.....	IV ?
4580.34	4	10	8	8	I A	5133.60	15	.....	.....	.....	V
4581.80	20	15	4	1	III	5145.63†	2	?	.....	.....	IV ?
4588.90	1	10	7	7	I A	5146.89†	15	?	.....	.....	IV ?
4594.82	4	1	.....	.....	IV	5149.21†	2	?	?	.....	IV ?
4597.10	5	1	.....	.....	IV	5149.93†	4	3?	2?	1	II
4625.91	2	2	1	.....	III	5154.20†	8	?	.....	.....	IV ?
4629.58	15	8	4	1	III	5156.49†	10	?	.....	.....	IV ?
4663.60†	12	8?	4?	1	III	5158.57†	2	?	?	.....	IV ?
4682.55†	9	?	2?	.....	III ?	5159.00†	2	1?	?	.....	IV ?
4693.36†	6	?	?	.....	IV ?	5165.30†	3	?	?	.....	IV ?
4698.56†	3	?	?	.....	IV ?	5166.27	2	.....	.....	.....	V

TABLE I—*Continued*

λ (Exner and Haschek)	Arc	Furnace			Class	λ (Exner and Haschek)	Arc	Furnace			Class
		High Temp.	Medium Temp.	Low Temp.				High Temp.	Medium Temp.	Low Temp.	
5176.22	20	15	12	2	III	5390.62†	2	1?	....	....	IV?
5192.53	4	....	....	....	V	5402.20	3	....	....	....	V
5210.20	3	tr	....	....	IV	5407.70	5	....	....	....	V
5210.97	3	tr	....	....	IV	5408.35†	2	2?	1?	....	III?
5211.91	3	tr	....	....	IV	5413.43	2	....	....	....	V
5212.85	25	4	3	....	III	5431.22	2	....	....	....	V
5219.20	2	....	....	....	V	5434.72†	2	3?	2?	....	III?
5222.67	4	1	....	....	IV	5437.17†	3	1?	1?	....	III?
5230.40	25	15	12	8	II	5444.80*	20	?	?	....	IV?
5235.32	15	12	10	4	II	5452.53	3	....	....	....	V
5248.02	15	15	12	5	II	5454.81	20	1	....	....	V
5250.12	7	....	....	....	V	5469.49	4	8	7	1	III A
5254.78	8	1	....	....	IV	5470.69	4	....	....	....	V
5257.75	10	1	1	....	III	5477.30	5	....	....	....	V
5264.40	2	1	....	....	IV	5483.59	40	20	20	20	I
5266.00	4	tr	....	....	V	5484.19	10	tr	....	....	V
5266.51 H*	10	2?	1?	tr?	II?	5489.81†	5	2?	1?	....	III?
5266.71 H*	25	15	12	8	II	5495.90†	2	1?	1?	....	III?
5268.70	10	2	2	....	III	5523.51†	8	4?	3?	2?	II?
5276.32	8	....	....	....	V	5525.23	4	....	....	....	V
5280.80	20	4	3	....	III	5530.99	10	12	10	6	II
5283.60	4	....	....	....	V	5546.60†	2	2?	?	....	III?
5287.78 H	3	tr?	....	....	V	5559.02†	2	2?	?	....	III?
5288.02 H	5	tr	....	....	V	5590.99	10	10	10	3	II
5301.20	15	15	12	8	II	5636.30	3	....	....	....	V
5312.80	8	1	tr	....	III	5637.91	3	....	....	....	V
5316.90	7	1	tr	....	III	5640.22	1	2	1	tr	III A
5321.89	2	....	....	....	V	5647.47	12	10	10	3	II
5325.40	10	2	1	....	III	5659.36	3	4	3	2	II
5326.06	4	1	tr	....	III	5688.82	2	3	2	1	II
5326.39	3	tr	....	....	IV	5770.62	2	....	....	....	V
5328.20	2	....	....	....	V	5830.32	4	....	....	....	V
5331.62	15	15	12	6	II	5846.78	2	....	....	....	V
5332.85	5	1	1	....	III	5881.32*	2	3?	3?	3?	I?
5333.82	5	1	tr	....	III	5890.71	12	8	8	2	III
5335.02	6	....	....	....	V	5915.74	10	8	8	2	III
5336.30	3	....	....	....	V	5935.61	6	6	6	1	III
5339.61	4	....	....	....	V	5946.73	5	2	1	....	III
5341.34	7	....	....	....	V	5984.40*	3	2	2	?	III?
5342.89	50	4	4	....	III		3	2	1	?	III?
5343.58	20	2	2	....	III	5992.11*	20	20	20	4	III
5347.63	4	....	....	....	V	6000.91	5	3	3	3	I
5349.23	4	....	....	....	V	6006.50	5	1?	....	....	IV?
5352.30	20	4	4	....	III	6007.85	5	....	....	....	V
5353.69	25	5	4	....	III	6049.34	6	....	....	....	V
5359.16 H	2	tr	....	....	IV	6070.80	2	....	....	....	V
5359.41 H	6	1	1?	....	III?	6082.67	15	3	2	....	III
5362.95	15	1	1	....	III	6086.84†	7	4	3	1?	II?
5369.83	20	15	15	12	I	6093.35	10	12	10	8	I
5381.31	5	5	4	1	III	6108.12	2	....	....	....	V
5381.92	6	....	....	....	V	6117.20	8	10	8	7	I

TABLE I—*Continued*

λ (Exner and Haschek)	Arc	Furnace			Class	λ (Exner and Haschek)	Arc	Furnace			Class
		High Temp.	Medium Temp.	Low Temp.				High Temp.	Medium Temp.	Low Temp.	
6122.90....	8	1 ?	.....	.....	IV ?	6450.51....	80	60	50	50	I
6189.20....	10	20	15	7	II A	6451.38....	3n	.....	.....	.....	V
6211.34†...	2	1 ?	?	.....	IV ?	6455.30....	40	4	3	.....	III
6231.20*...	10	12	10	2 ?	III	6478.10....	10	.....	.....	.....	V
6232.70....	2	1 ?	.....	.....	IV ?	6490.50....	6	7	6	1	III
6249.70....	8	6	6	2	II	6551.69....	3	4	4	.....	III
6257.81†...	6	2 ?	1	.....	III	6563.61....	40	20	20	6	II
6273.28†...	4	1 ?	tr ?	.....	III ?	6596.17....	12	.....	.....	.....	V
6282.89....	40	30	20	20	I	6617.30....	6n	.....	.....	.....	V
6320.62....	8	1	.....	.....	IV	6617.70....	3n	.....	.....	.....	V
6348.00....	10	.....	.....	.....	V	6624.00*...	2	3 ?	3 ?	.....	III ?
6351.66....	2	.....	.....	.....	V	6632.69....	15	10	8	4	II
6395.40....	8	.....	.....	.....	V	6679.03....	4	5	4	2	II
6396.71....	2	.....	.....	.....	V	6771.29*...	20	20	15	15	I
6417.99....	15	7	6	tr	III	6815.20*...	15	15	10	10	I
6421.91....	2	.....	.....	.....	V	6872.62*...	10	10	6	6	I
6430.10....	4	4	5	1	III	7016.82*...	3	3	3	3	I
6430.51....	2	.....	.....	.....	V	7053.11*...	8	8	6	6	I
6444.89....	2	.....	.....	.....	V	7085.25*...	15	12	10	12	I

REMARKS ON TABLE I

λ

3062.33 Concealed at high temperature by λ 3061.94.
3104.12 Probably double.
3137.47 Doublet, just resolved.
3140.08 Close doublet. Companion makes reversal unsymmetrical.
3168.19 and 3344.36 Both probably double.
3354.34 Concealed by reversal of λ 3354.51.
3361.72 Coincides with strong Ni line.
3409.05 Furnace line may be concealed by λ 3409.29.
3432.46 Probably double.
3443.31 Concealed by adjacent lines.
3474.40 Concealed by reversal of λ 3474.17.
3991.68 and 3991.83 Blend at high temperature.
4077.56 Doublet in arc. Only violet component appears in furnace.
4234.15 Close doublet, not fully resolved.
4953.32 Blend with Ni. Furnace line probably all Co.
5266.51 and 5266.71 Close blend.
5444.80 Very weak in furnace if present.
5881.32 Furnace line may belong to band spectrum.
5984.40 Doublet. Disturbed by band at low temperature.
5992.11 May be close doublet.
6231.20 Low-temperature line may belong to band.
6624.00 Furnace line may belong to band.
6771.29 to 7085.25 Photographed with 1-meter concave grating.

TABLE II

TEMPERATURE CLASSIFICATION OF NICKEL LINES

λ (Exner and Haschek)	Arc	Furnace			Class
		High Temp.	Medium Temp.	Low Temp.	
2981.80	20R	20R	15R	8r	II
2983.56	4	2	1	.....	III
2984.28	12R	12R	10r	5	II
2991.22	4	2	2	1	II
2992.71	20R	20R	15R	8r	II
2994.58	25R	25R	15R	8r	II
3002.58	100R	100R	75R	40R	II
3003.70	60R	60R	40R	20R	II
3012.11	75R	75R	30R	15r	II
3019.28	20R	20R	15R	8r	II
3029.36	3	1	.....	.....	IV
3031.98	10r	10r	5	2	II
3038.04	60R	60R	40R	20R	II
3045.15	10r	10r	6	3	II
3050.92	100R	100R	75R	40R	II
3054.42	50R	50R	30R	15R	II
3057.76	50R	50R	30R	15R	II
3064.75	25R	25R	20R	10r	II
3066.59	3	1	.....	.....	IV
3080.91	20R	20R	15r	7	II
3097.27	15r	15R	12r	6	II
3099.25	12r	12r	8	4	II
3101.67	100R	100R	60R	30R	II
3101.99	40R	40R	25R	15r	II
3105.60	15r	15r	10r	5	II
3107.83	4	3	2	2	I
3114.26	20R	20R	12r	8	II
3116.84	2	.....	.....	.....	V
3129.42	7	4	3	3	I
3134.22	60R	60R	40R	20R	II
3145.23	3	2	2	2	I
3145.82	8	8r	4	2	II
3151.33	4n	.....	.....	.....	V
3154.68	2	1	.....	.....	IV
3159.65	3	2	2	2	I
3164.30	2	1	.....	.....	IV
3165.64	3	2	2	2	I
3170.86	2	1	.....	.....	IV
3176.44	2	1	.....	.....	IV
3181.89	5	3	2	1	II
3183.14	3	1	tr	.....	III
3183.40	4	2	1	tr	II
3184.50	8	8r	4	2	II
3191.97	2	.....	.....	.....	V
3195.67	6	6	4	2	II
3197.22	10r	10r	8r	4	II
3199.44	3n	.....	.....	.....	V
3200.50	5	6	3	2	II
3202.21	5	1	.....	.....	IV
3207.05	4n	.....	.....	.....	V
3210.00	5	tr	.....	.....	V
3213.53	5n	.....	.....	.....	V
3214.17	7	1	tr	.....	III
3216.93	5	1	.....	.....	IV
3217.93	8	2	1	.....	III
3219.92	3	.....	.....	.....	V
3221.41	5	tr	.....	.....	V
3221.81	10r	15R	12r	6	II
3223.66	3	1	.....	.....	IV
3225.19	10r	12R	10r	5	II
3227.11	5	7	4	3	II
3233.06	25R	25R	20R	15r	II
3233.28*	4	?	.....	.....	IV?
3234.00	2	.....	.....	.....	V
3234.78	10r	12R	10r	5	II
3235.86	4	4	3	3	I
3243.20	25R	25R	20R	15r	I
3245.47	4n	.....	.....	.....	V
3248.56	8	10r	6	4	II
3249.55	6	5	4	4	I
3250.90	9	10r	6	4	II
3264.56	2n	.....	.....	.....	V
3268.21	4n	.....	.....	.....	V
3269.08	2n	.....	.....	.....	V
3271.25	10	10r	6	4	II
3282.03	5	tr	.....	.....	V
3282.81	8	8	5	4	II
3282.96	5	.....	.....	.....	V
3284.56	4	1	.....	.....	IV
3287.08	8	10r	6	4	II
3287.36	2	1	tr	.....	III
3305.10	6	1	.....	.....	IV
3307.16	2	.....	.....	.....	V
3309.56	2n	.....	.....	.....	V
3310.35	5	5	5	4	I
3312.49	10	2	1	.....	III
3313.15	4	.....	.....	.....	V
3315.82	30R	30R	25R	12r	II
3320.42	20R	20R	15R	8r	II
3320.92	6	tr	.....	.....	V
3321.36	2	.....	.....	.....	V
3322.50	15r	15R	10r	6	II
3326.80	4	1	.....	.....	IV
3327.52	4	.....	.....	.....	V
3328.85	5	4	4	4	I
3332.31	6n	.....	.....	.....	V
3335.72	2n	.....	.....	.....	V
3337.15	4	5	4	3	I

TABLE II—*Continued*

λ (Exner and Haschek)	Arc	Furnace			Class	λ (Exner and Haschek)	Arc	Furnace			Class
		High Temp.	Medium Temp.	Low Temp.				High Temp.	Medium Temp.	Low Temp.	
3338.90	3	1	1	.....	III	3476.80	2n	.....	.....	.....	V
3339.20	4n	.....	.....	.....	V	3478.00	2	.....	.....	.....	V
3359.30	8	1	.....	.....	IV	3478.42	3	tr	.....	.....	IV
3361.44	5	5	3	1	II	3479.36	3	.....	.....	.....	V
3361.75	20R	20R	15R	8r	II	3480.30	4	.....	.....	.....	V
3362.97	6	5	5	4	I	3483.98	25R	25R	20R	12r	II
3363.76	4	tr	.....	.....	IV	3485.25	2n	.....	.....	.....	V
3364.75	5	tr	.....	.....	IV	3486.09	10	10r	7	5	II
3365.92	15r	15R	10r	6	II	3488.43	2	.....	.....	.....	V
3366.32	20R	20R	15R	8r	II	3493.11	150R	150R	100R	60R	II
3366.95	10	2	1	.....	III	3496.47	5	tr	.....	.....	V
3368.05	8	8r	6	5	II	3501.02	25R	25R	20R	12r	II
3369.71	80R	80R	60R	30R	II	3502.73	8	8r	6	5	I
3372.19	15r	15R	12r	8	II	3507.85	8	8r	6	5	I
3374.42	15r	15R	12r	8	II	3510.52	80R	80R	50R	25R	II
3374.82	15	3	2	1	II	3511.76	2	2	1	.....	III
3375.70	2n	.....	.....	.....	V	3514.10	15	15R	10r	8	II
3376.46	4	.....	.....	.....	V	3515.21	150R	150R	100R	60R	II
3380.71	80R	80R	50R	25R	II	3516.33	8	1	1	.....	III
3381.01	15r	15R	12r	8	II	3518.80	8	1	1	.....	III
3387.54	3	4	4	3	I	3519.97	20R	20R	15R	8r	II
3391.20	50R	50R	40R	20R	II	3523.23	4	4	4	4	I
3393.10	100R	100R	70R	40R	II	3523.61	10	10r	8r	6	II
3396.31	6	.....	.....	.....	V	3524.68	200R	200R	125R	80R	II
3401.31	8	1	tr	.....	III	3526.67	3	.....	.....	.....	V
3403.58	8	2	1	.....	III	3528.13	15	15R	10r	8	II
3409.74	8	12R	10r	6	II	3528.70	3	.....	.....	.....	V
3413.66	25R	25R	20R	12r	II	3530.73	4	1	1	.....	III
3414.12	12r	15R	12r	8	II	3548.32	20r	20R	15R	10	II
3414.91	150R	150R	100R	50R	II	3551.71	8	8r	7	6	I
3420.88	5	6	5	4	I	3553.64	7	6	5	5	I
3421.49	7	1	tr	.....	III	3560.05	2	.....	.....	.....	V
3422.47	4	.....	.....	.....	V	3561.90	10	10r	8	6	II
3423.00	4	.....	.....	.....	V	3566.51	100R	100R	60R	30R	II
3423.87	50R	50R	30R	15R	II	3572.02	50R	50R	40R	20R	II
3433.74	70R	70R	50R	30R	II	3576.08	2	.....	.....	.....	V
3435.63	2	1	1	tr	II	3577.36	2	5	5	4	I A
3437.45	30R	30R	25R	15R	II	3588.07	12	12r	10r	7	II
3442.17	5	1	tr	.....	III	3597.86	50R	50R	40R	25R	II
3442.67	4n	.....	.....	.....	V	3602.41	15	15r	10r	8	II
3443.03	2n	.....	.....	.....	V	3604.41	1	3	2	.....	III A
3444.36	5	.....	.....	.....	V	3607.00	4	.....	.....	.....	V
3446.40	100R	100R	60R	35R	II	3609.48	15	15r	10r	8	II
3453.02	40R	40R	25R	15R	II	3610.61	60R	60R	50R	30R	II
3458.60	125R	125R	70R	40R	II	3612.90	30R	30R	15R	10r	II
3461.80	125R	125R	70R	45R	II	3619.52	150R	150R	80R	50R	II
3467.61	12	12R	8	6	II	3624.89	15	15r	8	6	II
3467.77	4	.....	.....	.....	V	3630.03	5	.....	.....	.....	V
3469.65	15	15R	10r	8	II	3635.10	12	8	6	6	I
3472.71	70R	70R	40R	20R	II	3641.75	4	5	5	5	I

TABLE II—*Continued*

λ (Exner and Haschek)	Arc	Furnace			Class	λ (Exner and Haschek)	Arc	Furnace			Class
		High Temp.	Medium Temp.	Low Temp.				High Temp.	Medium Temp.	Low Temp.	
3642.52	2	.....	.....	.....	V	4064.55	2	.....	.....	.....	V
3644.07	2n	.....	.....	.....	V	4075.00	2	5	4	2	II A
3647.85	2	2	2	1	II	4164.80*	1	6	5	2	II A
3657.87	2	.....	.....	.....	V	4195.72	4	.....	.....	.....	V
3662.10	8	6	6	6	I	4200.60*	5	1	1	1	I
3664.27	20	20R	12r	9	II	4201.89*	5	1	1	1	I
3666.16	2	1	1	.....	III	4231.19	5	.....	.....	.....	V
3668.36	3	.....	.....	.....	V	4284.84	6	tr	.....	.....	V
3669.40	12	12r	8	6	II	4288.15	15	tr	.....	.....	V
3670.60	20	20R	12r	9	II	4296.05	8	.....	.....	.....	V
3674.30*	{10	8?	8?	8	I	4325.52	2	.....	.....	.....	V
	{15	15r?	8?	5	II	4325.78	6	tr	.....	.....	V
3688.59	15	15R	12r	8	II	4330.90	2	.....	.....	.....	V
3689.43	2	.....	.....	.....	V	4331.83	12	8	6	3	II
3694.07	8	8	6	6	I	4356.07	3	6	3	1	II A
3697.05	3	.....	.....	.....	V	4359.76	10	1	.....	.....	V
3713.84	1	tr	.....	.....	IV	4368.47	2	1	.....	.....	IV
3715.65	2	.....	.....	.....	V	4384.70	5	.....	.....	.....	V
3722.64	15	15R	12r	7	II	4390.05	3	.....	.....	.....	V
3724.95	4	.....	.....	.....	V	4398.80	3	.....	.....	.....	V
3730.90	4	5	5	5	I	4399.78	3	.....	.....	.....	V
3736.95	15	15R	10	8	II	4401.02	3	.....	.....	.....	V
3739.40	10	8	8	7	I	4401.75	30	8	4	tr	III
3739.94	3n	.....	.....	.....	V	4410.66	4	1	tr	.....	III
3744.72	5	.....	.....	.....	V	4437.15	5	tr	.....	.....	V
3749.19	8	8	8	7	I	4437.78	2	.....	.....	.....	V
3772.67	6	6	6	6	I	4459.19	20	6	3	.....	III
3775.75	30r	30R	15r	10	II	4462.63	10	2	1	.....	III
3778.20	5	5	5	5	I	4470.64	15	4	2	.....	III
3783.72	30r	30R	15r	10	II	4520.15	4	4	3	1	II
3792.48	5	5	5	5	I	4547.11	5	1	tr	.....	III
3793.79	8	8	7	6	I	4547.38	3	.....	.....	.....	V
3807.35	35r	35R	20R	12r	II	4592.72	10	2	1	tr	III
3831.89	20	20R	12r	6	II	4600.56	6	tr?	.....	.....	V
3833.00	5	5	5	5	I	4605.17	12	3	1	.....	III
3858.51	40r	40R	30R	20R	II	4606.38	3	.....	.....	.....	V
3889.84	15	5	3	2	II	4648.85	15	3	2	tr	III
3909.10	8n	.....	.....	.....	V	4667.12†	2	?	1?	.....	III?
3912.47	8n	.....	.....	.....	V	4667.92	3	.....	.....	.....	V
3913.14	5	5	5	5	I	4686.39	5	2	1	.....	III
3944.29	12n	.....	.....	.....	V	4701.70	3	.....	.....	.....	V
3962.25	3n	.....	.....	.....	V	4703.97	4	.....	.....	.....	V
3970.65	10n	.....	.....	.....	V	4714.60†	25	6?	4?	2	II
3972.32	10	6	5	5	I	4715.95†	8	2?	1?	tr	II
3973.71	25	20R	10r	5	II	4731.98†	3	?	.....	.....	IV?
3974.82	10n	.....	.....	.....	V	4732.63	3	.....	.....	.....	V
3984.29	8n	.....	.....	.....	V	4752.59	4	1	1	.....	III
3994.15	3n	.....	.....	.....	V	4754.92	3	.....	.....	.....	V
4006.30	3	.....	.....	.....	V	4756.70	10	4	2	.....	III
4017.67	6n	.....	.....	.....	V	4762.82	3	6	4	2	II A

TABLE II—*Continued*

λ (Exner and Haschek)	Arc	Furnace			Class	λ (Exner and Haschek)	Arc	Furnace			Class
		High Temp.	Medium Temp.	Low Temp.				High Temp.	Medium Temp.	Low Temp.	
4764.15	4	1	tr	.....	III	5176.72	5	tr	.....	.....	V
4786.75	15	5	3	1	II	5184.78	4	1	.....	.....	IV
4800.01	1	1	tr	.....	III	5192.66	2	.....	.....	.....	V
4807.20	4	1	1	.....	III	5197.35	2	.....	.....	.....	V
4829.20	15	4	3	.....	III	5216.58	2	.....	.....	.....	V
4831.37	10	3	2	.....	III	5220.30	2	.....	.....	.....	V
4832.90	2	.....	.....	.....	V	5235.61	2	.....	.....	.....	V
4838.78	2	.....	.....	.....	V	5268.52	2	.....	.....	.....	V
4855.59	15	4	2	tr	III	5353.60*	3	?	?	1	II?
4857.57	2	1	.....	.....	IV	5371.60	4	2	.....	.....	IV
4866.47	10	3	2	.....	III	5411.41	4	.....	.....	.....	V
4871.01	2	.....	.....	.....	V	5424.87	4	5	3	2	II
4873.62	4	2	1	.....	III	5436.08	5	5	3	2	II
4904.61	10	3	2	.....	III	5462.69	4	.....	.....	.....	V
4912.19	2	.....	.....	.....	V	5477.12	50	20	15	15	I
4914.10	3	1	tr	.....	III	5495.15	2	.....	.....	.....	V
4918.52	4	2	1	.....	III	5510.20†	4	1?	.....	.....	IV?
4925.72	2	1	tr	.....	III	5553.93†	2	1?	.....	.....	IV?
4936.00	4	1	.....	.....	IV	5578.94	5	5	5	4	I
4937.45	4	4	2	.....	III	5588.09	5	4	3	3	I
4945.62	2	tr	.....	.....	IV	5589.58†	2	1?	.....	.....	IV?
4953.38*	3	.....	.....	.....	V?	5592.49	8	4	3	2	II
4971.50	2	.....	.....	.....	V	5593.99	4	2	2	.....	III
4980.34	12	3	2	.....	III	5615.01	5	.....	.....	.....	V
4984.31	10	2	1	.....	III	5625.52	4	.....	.....	.....	V
4998.40	2	1	tr	.....	III	5637.33	2	.....	.....	.....	V
5000.51	4	1	1	.....	III	5649.89	2	.....	.....	.....	V
5012.64	2	1	tr	.....	III	5664.23	3	.....	.....	.....	V
5017.73†	10	?	1?	.....	III?	5682.42	8	.....	.....	.....	V
5018.48	3	tr	.....	.....	IV	5695.19†	6	1?	.....	.....	IV?
5035.52	12	2	1	.....	III	5709.76	12	12	10	10	I
5042.37	4	.....	.....	.....	V	5712.10	5	5	4	3	II
5049.00	4	.....	.....	.....	V	5715.29	6	.....	.....	.....	V
5080.70	30	1	1	.....	III	5748.58	2	2	2	1	II
5081.29	25	1	1	.....	III	5754.89	10	8	7	4	II
5084.20	15	1	1	.....	III	5761.03	4	1	.....	.....	IV
5097.07	2	.....	.....	.....	V	5805.40	5	.....	.....	.....	V
5099.51	5	.....	.....	.....	V	5831.82	2	.....	.....	.....	V
5100.12	10	.....	.....	.....	V	5858.00†	7	1?	.....	.....	IV?
5115.57	8	.....	.....	.....	V	5893.11	12	8	6	2	II
5125.38†	4	?	?	.....	IV?	5997.02	3n	.....	.....	.....	V
5129.55	5	.....	.....	.....	V	5997.80	2n	.....	.....	.....	V
5131.93	3	.....	.....	.....	V	6007.54	3	3	2	1	II
5137.23	8	6	5	5	I	6053.91	2	.....	.....	.....	V
5139.43	3	.....	.....	.....	V	6086.53	5n	.....	.....	.....	V
5142.91	10	.....	.....	.....	V	6108.36	8	8	5	4	II
5146.61	12	.....	.....	.....	V	6111.22	2n	.....	.....	.....	V
5155.31	4	.....	.....	.....	V	6116.35	6n	.....	.....	.....	V
5155.90	9	.....	.....	.....	V	6163.60	5n	.....	.....	.....	V
5168.81	6	1	tr	.....	III	6175.69	8	.....	.....	.....	V

TABLE II—*Continued*

λ (Exner and Haschek)	Arc	Furnace			Class	λ (Exner and Haschek)	Arc	Furnace			Class
		High Temp.	Medium Temp.	Low Temp.				High Temp.	Medium Temp.	Low Temp.	
6177.00....	12	.....	.....	.....	V	6366.61....	4	tr	.....	.....	IV
6187.00....	2	.....	.....	.....	V	6378.40†...	5	1?	.....	.....	IV?
6191.48....	12	12	10	8	I	6483.08....	5	.....	.....	.....	V
6204.78....	2	2	1	.....	III	6586.52....	6	6	4	2	II
6224.18....	3	.....	.....	.....	V	6598.74....	3	tr	.....	.....	IV
6230.33....	2	.....	.....	.....	V	6635.32....	3	.....	.....	.....	V
6256.60....	15	15	12	10	I	6643.89....	20	20	20	20	I
6258.87....	2	.....	.....	.....	V	6767.99*...	20	15	12	10	I
6259.79....	2	.....	.....	.....	V	6772.55*...	5	.....	.....	.....	V
6314.89....	15	12	8	6	II	6914.83*...	3	3	3	3	I
6327.79†...	5	6?	4?	2?	II?	7122.54*...	5	.....	.....	.....	V
6339.40....	7	1	.....	.....	IV						

REMARKS ON TABLE II

λ	
3233.28	May be concealed at high temperature by λ 3233.06.
3674.30	Close doublet. Resolved at low temperature.
4164.80	Measured as λ 4164.70 in furnace spectrum. May be due to impurity.
4200.60, 4201.89	Very unusual type of Class I lines.
4953.38	Furnace line probably due to Co.
5353.60	Blend with Co at high and medium temperatures.
6677.99 to 7122.54	Photographed with 1-meter concave grating.

the cooler vapor near the ends of the tube would be very ineffective in recording its spectrum during the brief exposure at high temperature.

Class II.—This class includes a large proportion of the stronger arc lines. In the region of shorter wave-length, wide reversals of these lines are frequent, in some cases the reversal persisting even at low temperature. The reversals are usually much wider in the furnace than in the arc at moderate current, and the appearance of the lines from the two sources is very different. The estimates of relative intensity are made independently for arc and furnace, the scales being adjusted so that the stronger lines are given the

same intensity in the arc and in the high-temperature furnace. Lines of Class II usually remain strong at medium temperature in these spectra, but weaken at low temperature more than the lines of Class I, the distinction between the two classes being often based on this feature.

Class III.—These lines, whose characteristic is an initial appearance at medium temperature, form the most numerous class in the cobalt and nickel spectra. A large part of them show but slight change of intensity between the arc and the high and medium furnace temperatures, but some interesting exceptions appear, especially in the nickel spectrum. $\lambda\lambda$ 5080.70, 5081.29, 5084.20 are examples of very strong arc lines which appear only faintly in the furnace, but show at both high and medium temperature.

Classes IV and V.—These high-temperature lines, which are faint or absent in the furnace, are much more common in the nickel than in the cobalt spectrum. This is due partly to the frequent occurrence of the nebulous type among the nickel lines, but a large proportion of other strong arc lines, especially in the visible region, have not appeared in the furnace spectrum. In the cobalt spectrum, the lines in Classes IV and V are usually among the weaker arc lines which, however, are not given by furnace temperatures which show other lines as weak as these in the arc.

Lines relatively weak in the arc spectrum.—The number of lines, designated by "A" after the class number, for the production of which the arc appears to be less favorable than the furnace, is quite different for the cobalt and nickel spectra, the numbers being 40 and 6, or 5 per cent and $1\frac{1}{2}$ per cent, respectively, of the whole number of lines listed. This is in harmony with the greater relative richness of the cobalt spectrum in the furnace as compared with the arc, the proportion of lines in Classes IV and V being much smaller than for nickel.

DISTRIBUTION OF CLASSES ACCORDING TO WAVE-LENGTH

As the detailed examination of the cobalt and nickel spectra covers 4000 A, it seemed of interest to see how the classes are divided within successive equal intervals, as of 500 A, throughout

this range. This is shown in Table III, which gives the percentage of each class of the total number of lines within the given 500 A.

TABLE III

DIVISION OF LINES IN EACH 500 A AMONG FURNACE CLASSES
(The figures give percentage belonging to each class of the total number of lines within 500 A)

Class	Cobalt					Nickel				
	I	II	III	IV	V	I	II	III	IV	V
λ										
3000–3500	7	28	51	13	1	10	46	7	10	25
3500–4000	23	34	36	3	4	25	40	7	1	27
4000–4500	22	9	46	9	13	7	13	17	3	60
4500–5000	13	10	60	15	2	0	11	49	9	30
5000–5500	2	9	28	27	34	5	8	20	10	58
5500–6000	4	26	44	0	26	12	19	4	23	42
6000–6500	18	6	24	14	38	9	17	4	13	56
6500–7000	43	21	14	0	21	33	11	0	11	44

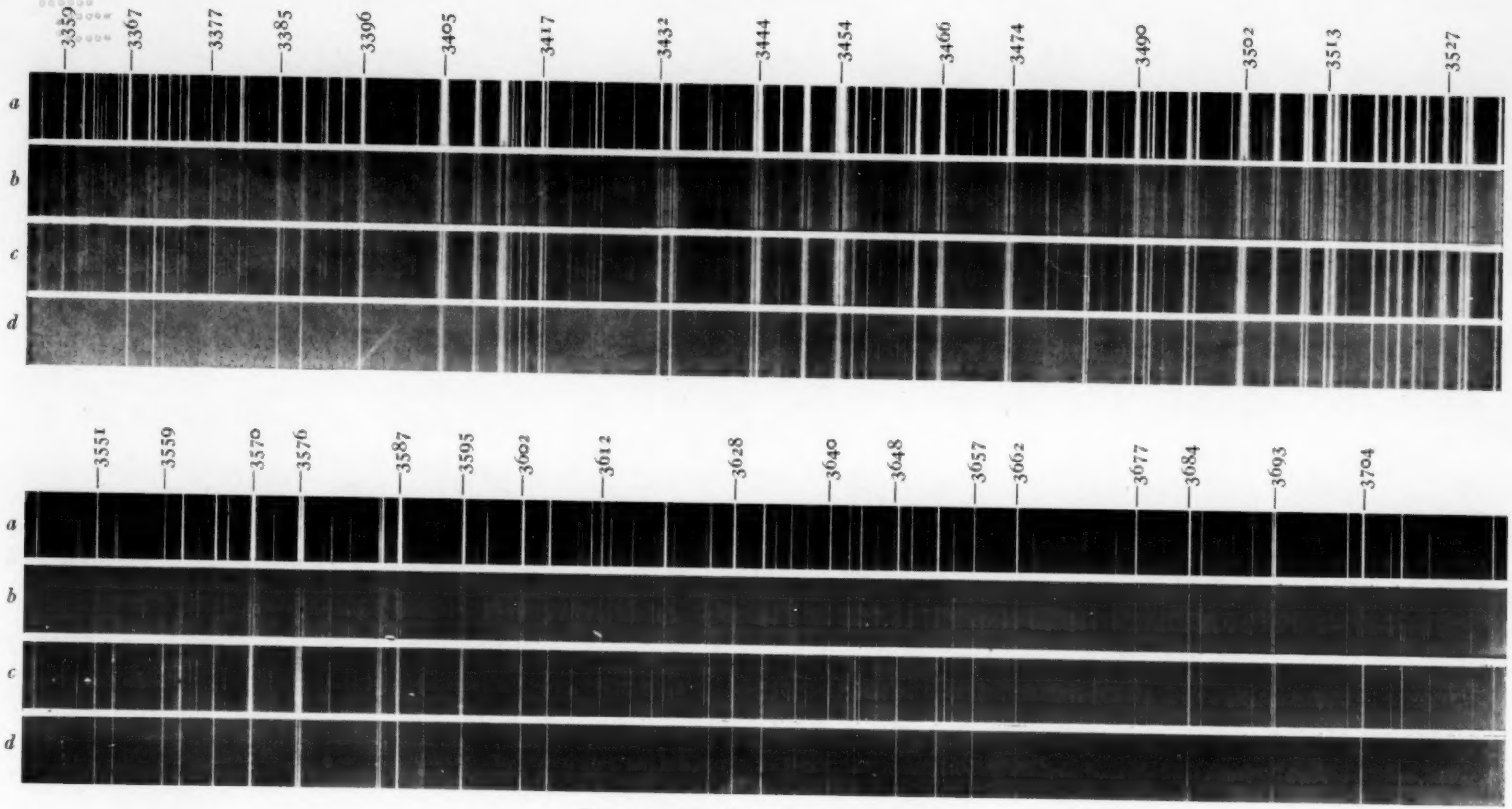
The columns of Table III do not show a regular change in the percentages of any class as we pass along the spectrum. In each spectrum there is a grouping of Class I lines in the extreme red, while at the other end we find a large proportion of the lines from λ 3000 to λ 4000 belonging to the low-temperature Classes I and II, the lines of Classes IV and V being in a decided minority at the violet end, especially for cobalt. This is in harmony with the feature noted for other elements, that the furnace spectrum, at least for the medium and high temperatures, is relatively rich in the region of shorter wave-length as compared with the arc. The greater part of the lines which require arc conditions occur farther toward the red. There is a definite tendency in the furnace, as in the spectra of other light-sources, for lines exhibiting a similar behavior to group in certain regions, this probably resulting from series relations which have not as yet been worked out, and the occasional preponderance of a single class in a given region may be a consequence of such groupings.

OCCURRENCE OF ENHANCED LINES IN THE FURNACE SPECTRUM

The behavior in the furnace spectrum of a number of lines listed by Lockyer[1] as enhanced seems to render it questionable whether

[1] *Tables of Wave-Lengths of Enhanced Lines*, Solar Physics Committee, 1906.

PLATE VII



Furnace and Arc Spectra of Cobalt

a. Arc spectrum of cobalt.
b. Spectrum of the electric furnace at 2600° C.
c. Spectrum of the electric furnace at 2300° C.
d. Spectrum of the electric furnace at 2100° C.

these are to be considered as of this class, or at least as a pronounced type of enhanced lines. The list follows with the furnace class of each line taken from Table I:

λ	Class	λ	Class
3817.01	II	3947.26	II
3843.85	III	3961.15	II
3851.09	I A	3977.34	III
3852.00	III	3987.25	I
3863.75	III	4014.09	II
3870.66	III	4023.55	III
3878.90	...	4077.56	III, V (double)
3898.54	III	4145.31	...
3904.23	V	4160.86	...
3925.33	III	4244.42	...
3929.43	III	4414.09	...
3946.75	II	4569.48	...

In the range from λ 3800 to λ 4100, the distribution of these lines as to furnace class is about what would be expected of the same number of lines taken at random, two lines of Class I even being found among them; while previous investigations have shown that typical enhanced lines, for which the difference between arc and spark intensity is large, are among the most difficult lines to obtain in the furnace. Exner and Haschek give most of these cobalt lines, as far as λ 4100, as of the same intensity in arc and spark. From the evidence at hand it seems probable that they are not enhanced lines of the regular type, but may be similar to a group of iron lines discussed in a former paper,[1] which appear in the furnace and in the spectra of flames whose temperature does not seem to be very high.

Among the enhanced lines of nickel as given by Lockyer, only λ 3889.84 appears in the furnace, this being a Class II line, of moderate strength in the arc spectrum.

EXPLANATION OF PLATE VII

In this plate, the cobalt spectrum from λ 3356 to λ 3720 is shown in two sections for the arc and for three furnace temperatures. Leading features are the variations in relative intensity for lines

[1] *Mt. Wilson Contr.*, No. 66; *Astrophysical Journal*, **37**, 239, 1913.

of different classes, the numerous wide reversals in the high-temperature spectrum, and the general richness of the low-temperature spectrum in this region.

SUMMARY

1. The furnace spectra of cobalt and nickel have been examined from λ 3000 to λ 7100 with regard to the temperature at which a given line appears and its rate of increase in intensity as the temperature rises. The classification of lines on this basis includes 840 lines in the cobalt spectrum and 423 in that of nickel.

2. The leading features of the various furnace classes are discussed, these being in the main similar to those observed in the furnace spectra of other elements.

3. The number of lines relatively fainter in the arc than in the furnace is larger for cobalt than for nickel; while the nickel spectrum shows a large proportion of lines, many of them of nebulous type, which require the arc conditions to give them strongly.

4. An examination of the distribution of furnace classes through the spectrum shows a relative richness of the furnace spectrum at the violet end, and a tendency for lines of similar character to group in certain regions.

5. A number of lines, especially of cobalt, which have been classified as enhanced appear in the furnace spectra, thus indicating that they may not be enhanced lines of pronounced type.

Mount Wilson Solar Observatory
June 1915

Minor Contributions and Notes

NICKEL DEPOSITS ON GLASS MIRRORS FOR ULTRA-VIOLET PHOTOGRAPHY

In the *Astrophysical Journal* for December 1911, I described a method for the preparation of the nickel-on-glass mirror which I used for the ultra-violet photography of the moon.

The difficulty in making successful electrolytic deposits of this metal on a silver film results from the circumstance that the nickel comes down under tension and strips the silver film from the surface. I succeeded, however, by the use of a very dilute solution of the double sulphate of nickel and ammonium, to which a small amount of ammonia was added, in obtaining deposits sufficiently thick to answer the purpose. The deposit was not very bright, however, resembling a slightly tarnished iron surface.

Since the publication of the paper above referred to, some experiments made by Hollard[1] on the behavior of various salts of nickel, made it appear worth while to renew the experiments with silvered glass mirrors. Hollard found that in the case of electroplating on metals very superior results were obtained with a solution of nickel fluor-borate, it being possible to obtain much thicker deposits without the "flaking-off," than was possible with the solutions used in commercial processes.

I prepared a small quantity of this substance, and obtained such superior results on small silvered strips of glass that experiments on a large scale were at once commenced. The method of preparation of the nickel fluor-borate is as follows: A hot solution of 350 gm of sodium carbonate in one liter of water is added to a lukewarm solution of 600 gm of nickel sulphate in 5.5 liters of water. The precipitate thus formed is to be washed until the filtrate shows no reaction (white precipitate) with barium chlorate. As it filters very slowly the quickest way to get rid of the sodium

[1] *Bulletin Soc. Encouragement* (Geneva), **118**, 24, 1912.

sulphate is to allow the precipitate to settle for two or three hours in tall jars, pouring off the clear solution and then filling up the jars again. This process must be repeated three or four times, after which the material may be put into the filters, and subjected to further washing, until the barium chloride gives little or no reaction.

Dissolve 130 gm of boric acid in 300 cc of boiling water, heating the liquid until the solution is complete. Cool rapidly by immersing the beaker in water, stirring constantly. The pasty mass thus obtained is put in a wax or gutta-percha beaker (which can be made from an old hydrofluoric acid bottle by cutting off the top) and 250 gm of commercial hydrofluoric acid added. To this solution the nickel carbonate is to be added, a little at a time. Owing to the great bulk of the latter it is best to pour about 20 cc of the acid into a wax dish of, say, 300 cc capacity, and then add the paste until a little remains undissolved. The solution can then be poured into a glass vessel and a second lot prepared. At the end the solution must be distinctly milky, that is, there must be an excess of the carbonate. The solution is not yet complete and must be stirred rapidly overnight or for, say, fifteen hours by an electric motor with a bent glass tube fastened to its axle. It is then filtered from the undissolved carbonate. In working with the hydrofluoric acid it is necessary to use the greatest precautions. A single drop falling on the root of the finger nail, even if washed off instantly under the tap, may give rise to a very bad inflammation of the whole finger which lasts for ten days or more. If an accident does occur, *sodium carbonate and not ammonia* must be used at once for the neutralization. Apparently the frightful nature of the burns occasioned by this acid are not generally realized, and the use of a pair of rubber gloves cannot be too strongly advised.

Hollard recommends that the solution be subjected to electrolysis for an hour with a copper cathode and nickel anode before being used for the work desired. In my own case I utilized this preliminary run for the preparation of my nickel anode.

As I happened to have only a sheet of nickel about 20 cm square, I decided to make the anode of nickel-plated brass. A thick piece of brass rod provided with a binding post was riveted to the center of a brass disk 40 cm in diameter. Nickel was deposited on this

from the solution, using a current of about 5 amperes. Six dry cells were found to be about right for the deposition. Of course a nickel disk would be preferable. Preliminary experiments were first made on small strips of plate glass silvered by Brashear's process. The silver film was dried, and the light deposit of white powder wiped from it with a pad of dry absorbent cotton. It was found that with two dry cells a firm, hard, and very brilliant deposit of nickel could be obtained in about fifteen seconds. Previous to the deposition of the nickel the sun's disk could be seen of a deep blue color through the silver film. The electrolytic deposit rendered the film quite opaque.

To determine the effect of varying the time of deposition a strip was immersed to a depth of 1 cm for five seconds, then to a depth of 2 cm for an additional five seconds, and so on until five or six patches of nickel of varying thickness had been obtained. It was found that the five-second deposit was not nearly so bright as the others, it being distinctly brown by comparison. This is rather curious, as it is backed by the highly reflecting silver. It seems as if a certain definite thickness must be reached before the nickel film acquires its full reflecting power, and if we stop short of this point the loss due to insufficient thickness is by no means completely compensated by the reflection from the underlying film of silver.

Experiments were next made with more dilute solution, and it was found that the solution as first prepared (some 2 liters in volume) could be diluted with six or eight parts of water and still yield perfectly satisfactory deposits. In nickeling my large mirrors I have always used the diluted solution.

A large circular wash-basin of white enameled iron was used for the electroplating work, the silvered glass mirror being laid flat in the basin, with the film up. Contact with the silver film was made by pressing a piece of very thin platinum foil against the surface with the finger. The foil was soldered to a copper wire which passed through a glass tube.

At first I used two dry cells, as with the smaller plates, but the deposits on the large mirror were very bad. The metal came down in irregular patches; some portions of the surface received no

deposit at all, and others were colored bright yellow. It was suspected that the trouble resulted from insufficient current-density. Similar deposits were obtained on small plates, if an ordinary carbon filament lamp was included in the circuit.

I then measured the current-density in the case of the small plates with a milliamperemeter.

With an immersed surface measuring 2×3 cm a current of 33 milliamperes was obtained, or 5.6 milliamperes to the square centimeter. This current-density gave beautifully bright deposits. The area of the large mirrors was then measured, and calculations showed that, in this case, a current of about 5.6 amperes would be necessary, for the radii of the two mirrors were 18 and 20 cm respectively. In the case of these mirrors, with two dry cells only, an amperemeter showed 1.2 amperes, four cells gave 2.8 amperes, while 6 cells gave 5.6 amperes, with a distance of about 3 cm between the anode disk and the silver film. Six cells were accordingly used in all subsequent operations. It was found best to make the contact between the platinum foil and the silver film before lowering the anode into the solution. If this was not done it often happened that the film was destroyed at the point of contact and the flow stopped. This resulted from the circumstance that the current-density at the first point of contact, formed between the platinum and the film, was too great for the latter to carry. Forty seconds were sufficient for a good deposit, in the case of the dilute solution, and the film was uniformly brilliant over its entire surface. In the case of very large mirrors it would be advantageous to have a number of contacts around the rim. The deposition can be watched by moving the anode from side to side. During the first few seconds the metal comes down in small patches of irregular form, which are brownish in color. These rapidly brighten, the spaces between them fill up, and in twenty or thirty seconds the reflecting power appears uniform over the entire surface. The anode is then lifted out, the disk removed from the solution and washed under the tap.

The concave mirror which I am now using for ultra-violet lunar photography was figured by J. E. Mellish, of Williams Bay, Wisconsin. Its focal length is 55 ft., and the definition is perfect.

The deposition of the nickel film does not affect the resolving power, as far as I can see.

Some experiments were made on the current-carrying capacity of thin silver films, a point which is of importance in the case of large mirrors, with but a simple electrode applied to the silver surface. A narrow strip of glass was silvered with a film of such thickness that a window backed by a brightly lighted sky appeared of a dark blue color through the film. The silver was scraped from the middle portion of the plate with the exception of a strip 1.5 mm in width and 5 or 6 mm in length. It was found that the narrow strip carried a current of 1 ampere, but burned out at 1.2 amperes. If a drop of water covered the strip, the current could be raised to 2 amperes before the film was disrupted, the final disintegration of the film resulting from the explosion of stream bubbles. With a circle of contact 1 cm in diameter a current of 20 or 30 amperes could probably be delivered to the silver film in the case of the electroplating process, which would answer for a mirror very much larger than the ones used in the present case.

It is perhaps worthy of mention that the silver films were deposited with a much smaller quantity of the solution than is usually recommended for Brashear's process. The 16-inch mirror, provided with a rim of paraffin paper, was silvered with but 5 gm of silver nitrate and 2.5 gm of caustic potash, each dissolved in about 70 cc of water. This is less than one-tenth of the amount customarily used for a 24-inch mirror. I mention this point, as repeated trials may be found necessary before a first-class deposit of nickel is obtained.

These experiments form a part of an investigation now under way of the distribution on the moon's surface of the material, probably sulphur or sulphur-bearing rocks, which is shown only in photographs made with ultra-violet light.

I have been aided in this work by a grant of $200.00 from the Gould Fund of the National Academy of Sciences.

R. W. Wood

East Hampton, Long Island, N.Y.
August 1915

THE DISTRIBUTION AND SOME POSSIBLE CHARACTERISTICS OF THE SPECTROSCOPIC BINARIES OF CLASS M

Attention may be called to the distribution of the known binary stars of Class M. A comparison with the Cepheid-Geminid variables in this and other respects is also of some interest.

From data available to date ten stars of Class M have been found to be binaries or to have variable radial velocities as follows:

β Andromedae	F Centauri
$+65°369$	$+66°878$
α Orionis	α Scorpii
η Geminorum	δ Sagittae
ϵ Muscae	μ Cephei

With the exception of $+66°878$, these binaries show a strong preference for the Milky Way in contrast to the nearly uniform distribution of the other stars of Class M over the sky.

The average galactic latitude of the nine stars is 9°.

Omitting β Andromedae, which is 30° from the central line, the average for the remaining eight is less than 7°.

Three of these stars are variable with small ranges of brightness of the order of the Cepheids. These stars have also very small proper motions, comparable in this respect with the Cepheids.

Only two orbits are available, of α Orionis and α Scorpii.[1] As both of these stars have very small proper motions, it is interesting to compare their orbits with those of the Cepheids, especially as one star is known to be variable in brightness.

The principal elements of the two Class M stars are given below:

	Mag.	P	e	$\bar{\omega}$	$\frac{m^3 \sin^3 i}{(m+m_1)^2}$	$a \sin i$	P.M. α	P.M. δ	V
α Orionis..	0.9	6.70 y	0.24	255°	0.0029	70,000,000 km	$+0^{s}.0019$	$+0''.008$	+5.4 km
α Scorpii..	1.2	5.8	0.20	289	0.0020	60,490,000	− .005	− .003	+6.1

[1] Bottlinger, in *Astronomische Nachrichten*, **187**, 33, 1911, called attention to Ludendorff's observation of the similarity of the orbits of these two stars.

The points regarding these Class M stars to which I would direct attention are:

1. The strong preference of these binary stars of Class M for the Milky Way.

2. The difference of the angles of periastron of the two orbits from the majority of the Cepheids by approximately 180°.

3. The much larger values of $a \sin i$ of the two stars of the M-type group and their much longer periods than corresponding elements for Cepheids.

4. The similarity of the two M-type stars to the Cepheids in the matter of masses of the secondary bodies.

5. The generally small proper motions of the M-type binaries.

6. The generally small radial velocities of these M-type stars. The average for the ten is 10 km. Omitting the large velocity of μ Cephei, the average for the remaining nine is 7 km. This is much below the average for the Class M stars found by Campbell, viz., 17 km.

There is some uncertainty in the velocities of the systems of four of these stars, but it can hardly affect the foregoing conclusion greatly.

It is fully recognized that the data are very meager and sufficient only to suggest possible characteristics of the group. There seems, however, reason to believe that some of these may prove to be characteristics of this class of stars and that efforts in obtaining more observations and orbits will be well repaid.

It seems highly probable that α Scorpii will be found to vary also in brightness through a small range.

C. D. Perrine

Observatorio Nacional Argentino
Córdoba
May 8, 1915

EDITORIAL NOTE

The attention of contributors and all others concerned is directed to the fact that the duties of managing editor of the *Astrophysical Journal*, which have been carried by Mr. Gale for the past six volumes, have been resumed by Mr. Frost, beginning with the present volume.

Manuscripts, proof sheets, books for review, and all editorial correspondence should be addressed to

EDITORS OF THE ASTROPHYSICAL JOURNAL
YERKES OBSERVATORY, WILLIAMS BAY, WISCONSIN

Business correspondence should be addressed as heretofore to

THE UNIVERSITY OF CHICAGO PRESS
CHICAGO, ILLINOIS